TWEED
SHIRE COUNCIL

Murwillumbah CBD Levee & Drainage Study

Draft Report

Volume 1 of 2: Report Text & Appendices

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Catchment Simulation Solutions

Murwillumbah CBD
Levee & Drainage Study

Draft Report

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Executive Summary

Murwillumbah is located in northern New South Wales and is home to over 8,000 people. The township is surrounded by a number of waterways including:

- The Tweed River;
- The Rous River; and,
- Mayal Creek.

The proximity of the township to these waterways has resulted in inundation of the main township on a number of occasions, most notably in 1954, 1974 and more recently in 2017. The *'Tweed Valley Floodplain Risk Management Plan'* (*WBM BMT*) was prepared in 2014 to assist in better managing the flood risk across the broader Tweed Valley. A recommendation of the *Plan* was for a detailed local drainage study to be commissioned for Murwillumbah to investigate the flood risk within the township associated with drainage behind the levee. A levee overtopping study was also recommended to improve the understanding of hydraulic behaviour around the levee.

Accordingly, Tweed Shire Council commissioned Catchment Simulation Solutions to undertake a detailed study to define flooding and drainage behaviour within the CBD associated with local catchment runoff as well as levee overtopping. A key objective of the study was to also identify the merits of implementation a range of potential measures that to assist in better managing the flood risk for those sections of the town contained behind the levee system.

The Existing Flooding and Drainage Problem

The extent of the existing flooding and drainage problem was quantified using a computer flood model of the Tweed and Rous Rivers. The flood model was originally developed as part of the *'Tweed Valley Flood Study'* (BMT WBM, 2005). However, the model was updated as part of the current study to include a more detailed description of the terrain, the levees, and the stormwater drainage and pump systems.

The computer model was used to simulate a range of design floods and the outputs from the model were used to quantify the potential impact of flooding on people and property behind the levees. The outcomes of the modelling determined that:

- Inundation behind the levees can occur in events as frequent as a 20% AEP (1 in 5 year ARI) flood. The areas most susceptible to frequent flooding are concentrated in the vicinity of Knox Park. However, inundation is also predicted in low lying sections of Proudfoots Lane as well as Williams Street.
- The southern section of the Commercial Road levee is predicted to be overtopped during the 1% AEP (1 in 100 year ARI) flood and floodwaters are predicted to be at the crest of the East Murwillumbah levee during the 1% AEP flood.
- All three levees protecting the town would be overtopped during a 0.2% AEP event. Over 3 metres depth of water is predicted behind the Commercial Road levee.

A flood damage assessment was completed as part of the study and determined that the average annual cost of flooding would be $1.1 million if the "status quo" was maintained.

Options for Reducing the Flooding and Drainage Problems

A range of options were considered to help better manage the existing flooding and drainage risk. Each option was evaluated against a range of criteria to provide an appraisal of the potential feasibility of each option. This included the impact of each option on existing flood behaviour, economics as well as emergency response benefits.

Based upon the outcomes of the detailed evaluation, the options outlined below are recommended for implementation/further investigation:

- Remediation of the Commercial Road levee, including installation of a formalised spillway to reduce the potential for levee overtopping and scour, and provide a controlled entry point for water into the township away from existing development.
- Installation of a new pump system for the area behind the Dorothy Street levee to assist in reducing flood levels behind the levee and allowing water to drain from behind the levee following the flood.
- Temporary flood barriers that could be installed by commercial property owners before a flood to prevent the ingress of floodwaters.
- Local Flood Plan / flood intelligence updates that aims to take advantage of the detailed flood information produced as part of the study to allow the SES to refine their emergency planning.
- Flood warning system upgrades to provide improved dissemination of flood warning information to emergency services and the broader community.
- Community education so that the community better understands their flood exposure and how to respond during future events.

It should be noted that although each of the options investigated will assist in reducing the existing flood risk, there will be no one option (or combination of options) that will eliminate the flood risk across Murwillumbah. Therefore, there will still need to be an ongoing focus on emergency response and community education activities to ensure the residual flood risk is well managed.

1 INTRODUCTION

1.1 Study Area

Murwillumbah is located within the Tweed Shire Local Government Area (LGA) in northern New South Wales and is home to over 8,000 people. As shown in **Figure 1**, the township is surrounded by a number of waterways including:

- Tweed River, which is located to the south and east of the town;
- Mayal Creek, which is located to the north-east of the town; and,
- Rous River, which is located to the north-west of the town.

Lavender Creek also drains through the town and discharges to the Tweed River under Commercial Road.

The main township is protected from flooding from the Tweed and Rous Rivers by a number of levee systems. The location of each levee is shown in **Figure 1** and includes:

- Commercial Road Levee.
- East Murwillumbah Levee.
- Dorothy Street / Brothers Levee.

South Murwillumbah, which is located on the eastern floodplain of the Tweed River, is also protected by a levee. However, this levee system does not fall within the current study area.

During rainfall events across Murwillumbah, runoff is collected via a piped stormwater system and discharged to the Tweed and Rous Rivers through a number of pipes under the levee system. These outlets are fitted with flood gates that close when there are elevated water levels within the river system.

Two pumps also assist in draining the CBD during rainfall events by pumping runoff from the Lavender Creek and CBD subcatchments to the river. The main pump is located near the Lavender Creek crossing of Commercial Road and the second pump is located adjacent to Wharf Park near its intersection with Tumbulgum Road (refer **Figure 1**).

1.2 Purpose of Study

Major floods in 1954 and 1974 resulted in inundation of the Murwillumbah CBD. In the 1990's the Commercial Road Levee was raised and since this time, the township has not been inundated as a result of floodwaters overtopping the levee system. Nevertheless, there is still potential for the levee system to be overtopped during large Tweed River floods, such as the 1954 event. Moreover, the lack of any large floods since the levee was raised means that the location where the levee might first overtop and how water would be distributed across the CBD is not well understood.

Although Murwillumbah has not been subject to inundation associated with overtopping of the levee system, the township has been flooded from local catchment runoff in recent years. This typically occurs during Tweed River floods when levee floodgates are closed and local catchment runoff is unable to discharge freely into the river system. This includes flood events in 2008, 2012, 2013, 2014 and 2016.

In an effort to better understand the flood risk across the Tweed River catchment (including Murwillumbah), Tweed Shire Council commissioned the *'Tweed Valley Flood Study'* (*WBM BMT, 2009*). This was followed by the *'Tweed Valley Floodplain Risk Management Study'* (*WBM BMT, 2014*) and the *'Tweed Valley Floodplain Risk Management Plan'* (*WBM BMT, 2014*). A recommendation of the *'Tweed Valley Floodplain Risk Management Study'* was for a detailed local drainage study to be commissioned for Murwillumbah to investigate the flood risk within the township associated with drainage behind the levee, the operation of the flood pumping stations and identify potential measures to mitigate local drainage issues. A levee overtopping study was also recommended to improve the understanding of hydraulic behaviour around the levee and inform future decisions on levee works.

Accordingly, Council commissioned Catchment Simulation Solutions to undertake a detailed study to define flooding and drainage behaviour within the CBD associated with local catchment runoff as well as levee overtopping. This includes information on flood discharges, levels, extents, depths and velocities as well as hydraulic and hazard categories for a range of historic and design floods. The study also assesses potential measures that could be implemented behind the levee to assist in reducing the potential impacts of flooding on the community.

The report comprises two volumes:

- Volume 1 (this document): contains the report text and appendices
- Volume 2: contains all figures/maps

2 Background Information

2.1 Overview

A range of data was made available to assist with the preparation of *Murwillumbah CBD Levee Drainage Study*. This included previous reports, drainage information, levee plans and topographic data.

A description of each dataset is provided in the following sections.

2.2 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 Murwillumbah.

2.2.1 Tweed Valley Flood Study (2009 Update) (2009)

In 2005, the first edition of the *'Tweed Valley Flood Study'* was published 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 from approximately 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. The township of Murwillumbah formed part of this study area. The study focussed on defining "main stream" flood behaviour (i.e., flooding associated with water overtopping the banks of major waterways). Inundation associated with overland flow and stormwater runoff from short-duration, high-intensity storm events was not assessed as part of the study.

The *'Tweed Valley Flood Study'* (*2009 Update*) (*WBM BMT, 2009*) was subsequently prepared to incorporate improved topographic data of the catchment. Both the hydrologic and hydraulic models were also updated to take advantage of improvements in modelling technology in the intervening four-year period.

The 2005 Flood Study was based on hydrological outputs from a RORB model developed by the Public Works Department (PWD) in 1989. However, the 2009 update included the development of a new WBNM hydrologic model to define the hydrology across the catchment under existing conditions. A total of 207 subcatchments were delineated and used to represent the hydrologic properties of the Tweed River catchment within the WBNM model.

A hydrodynamic, 1D/2D TUFLOW hydraulic model of the Tweed River system was originally developed as part of the 2005 Flood Study. This TUFLOW model was updated as part of the 2009 update to incorporate a Digital Terrain Model (DTM) developed from aerial laser survey data that was gathered for the Tweed River floodplain in 2007. Flows across the floodplain and in the wider, lower reaches of the Tweed River were modelled in 2D based on a 40m x 40m 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.

Joint calibration of the WBNM hydrologic model and TUFLOW 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 good reproduction of the historic flood information.

The calibrated models were used to simulate the 5, 20, 100 and 500 year ARI design floods, as well as the Probable Maximum Flood (PMF). The study determined the critical storm duration for the Tweed River at Murwillumbah to be 36-hours.

The Flood Study report documents and maps the results of the modelling, including design flood levels, depths, extents, and high and low flow areas across the Lower Tweed River floodplain. Peak floodwater depths for the 100 year ARI flood extracted from the flood study are reproduced in **Figure 2**.

Key findings from the study regarding flood behaviour in and around the township of Murwillumbah includes:

- Murwillumbah is protected by flooding from the Tweed River by a levee system which provides flood immunity above a 20 year ARI event, but begins to overtop in the 100 year ARI event.
- Overtopping of the levee first occurs at Murwillumbah Bridge when levels in the Tweed River reach approximately 6.8 mAHD. The peak 100 year ARI flood level at the bridge is 6.91 mAHD.
- At the peak of the 100 year ARI flood, inundation in Murwillumbah extends west to about Nullum Street and north to Wharf Street. Floodwater depths up to 1.5 metres are predicted in some areas of Knox Park and sports fields to the south of the CBD, and depths up to 2.5 metres are predicted at the eastern end of Wharf Street.
- Velocities through Murwillumbah during the 100 year ARI flood are generally low (i.e., less than 0.1 m/s).

It is noted that the relatively large grid size (i.e., 40 metres) employed in the hydraulic modelling means that a detailed understanding of the local movement of floodwaters across Murwillumbah is not provided by the TUFLOW model and a more detailed model is necessary to more 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 current study.

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

BMT WBM Pty Ltd also prepared a separate report to document the findings of climate change investigations undertaken as part of the *'Tweed Valley Flood Study (2009 Update)'*.

The two climate change scenarios that were selected for assessment based on the 100 year ARI flood were:

- 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 medium and high level climate change impact scenarios were modelled using the WBNM and TUFLOW models from the *'Tweed Valley Flood Study (2009 Update)'*. The results of the climate change simulations were compared against the existing 100 year ARI design flood levels. For the high impact climate change scenario, it was determined that design 100 year ARI flood levels would generally be:

- 0.5 to 1 metre higher along the Tweed River from Murwillumbah to the river mouth;
- 1 to 1.5 metres higher along the Tweed River from Byangum to Murwillumbah; and
- More than 2.5 metres higher in the Murwillumbah CBD (behind the levee).

The report explained that the higher flood levels upstream of 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 100 year ARI flood levels is more pronounced around and upstream of Murwillumbah.

For existing climate and catchment conditions, the study predicted that that the levee would be overtopped for approximately 3 hours, with a peak depth of approximately 0.1 metre over the levee crest, during the 100 year ARI flood. This limits depths of inundation in most areas behind the levee to less than 0.5 metre, with the exception of some deeper, localised ponding in Knox Park and at the Commercial Road /Wharf Street intersection.

However, under the high climate change scenario, existing 100 year ARI design flood levels in the Tweed River at Murwillumbah increase by approximately 1.1 metres. This results in a greater distribution of flow across the levee which, in turn, produces a substantial increase in flood levels and depths in the township. More specifically, in the high climate change scenario, the levee was predicted to be overtopped for approximately 8 hours with a peak depth of about 1.2 metres over the levee crest. Consequently, the "basin" behind the levee is completely inundated, with floodwater depths through the CBD typically between 4 and 5 metres. Accordingly, climate change has the potential to significantly increase the severity of flooding across Murwillumbah.

2.2.3 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 minimise the community's exposure to flood risk. 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)* (refer Section 2.2.4).

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)'*. Council adopted a climate change flood scenario which accounts for a 10% increase in rainfall intensity and a sea level rise of 91cm for the 100 year ARI event. 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 is $22.5 million.

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

- The Murwillumbah levee system is overtopped under existing conditions during the 100 year ARI flood. However, water is predicted to drain away from the levee towards Knox Park. This results in 100 year ARI flood levels within the township being lower than the river level (and those on the eastern floodplain of the river).
- Flood storage areas include parts of the Rous River floodplain and Murwillumbah business centre.
- There are some areas of flood fringe, including around Willard Park on the northern side of Murwillumbah.
- West Murwillumbah is considered to have a low flood risk.
- Most of the Murwillumbah area is subject to high depth hazard (i.e. depths exceeding 1 metre) in a 100 year ARI flood. However, depths in the main township are somewhat lower due to the levee system which reduces the ingress of water into Murwillumbah.
- 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.
- Most locations within Murwillumbah grade up to higher ground and evacuation will be possible during most events up the 100 year ARI event. However, most evacuation routes within the township are cut before warnings can be issued in a PMF event.
- Evacuation from the lower areas of Murwillumbah is reliant on the community's preparation and adherence to evacuation orders prior to the onset of inundation, as flood levels behind the levee rise rapidly once overtopping begins.

The floodplain risk management study did not recommend any flood modification or property modification measures for Murwillumbah. However, it did recommend the commissioning of a local drainage study for Murwillumbah CBD to quantify overland flooding / stormwater risks behind the town levee, to optimise the operation of the pump stations, to identify potential drainage mitigation measures and to inform development planning within the township. The study also recommended that a levee overtopping analysis be completed to improve the understanding of hydraulic behaviour around the levee and inform decisions about future levee works.

Response modification measures recommended for the whole Tweed River floodplain, including Murwillumbah, include improved flood education, emergency planning and development planning. The study highlights the need for future development plans for any infill development within the Murwillumbah township to appropriately consider flood risk and evacuation planning.

2.2.4 Tweed Valley Floodplain Risk Management Plan (2014)

The *'Tweed Valley Floodplain Risk Management Plan'* was prepared by BMT WBM Pty Ltd and draws on the results documented in the *'Tweed Valley Floodplain Risk Management Stud*y'. The Plan provides a prioritised plan to implement recommended measures in terms of relative priorities, estimated costs, key agency responsibilities, and benefits of implementation.

The recommended measures specific to the Murwillumbah township, namely a detailed local drainage study and levee overtopping study, were assigned as high and medium priority, respectively.

2.3 Topographic Information

2.3.1 Digital Elevation Model

Figure 3 provides a Digital Elevation Model (DEM) of Murwillumbah. The DEM shows the variation in ground surface elevation and was developed from 2014 LiDAR information. The LiDAR has a stated horizontal accuracy of 0.8 metres and a vertical accuracy of 0.3 metres.

Figure 3 also shows that the elevated terrain to the north and east of the CBD combined with the levees to the south and east of the CBD forms a topographic "bowl". With the exception of Lavender Creek, the lowest point in this "bowl" is Knox Park, which is located at an elevation of about 2 mAHD. The ground surface elevations typically grade up in all directions away from Knox Park.

Similarly, the elevated terrain and levee systems create topographic bowls across East Murwillumbah as well as the area behind the Dorothy Street / Brothers levee across West Murwillumbah.

2.4 Levee Information

Council provided plans for each of the three levee systems protecting Murwillumbah. Key characteristics of each levee are summarised below. As noted in Chapter 1, the East Murwillumbah levee was not included as part of the current study.

2.4.1 Commercial Road Levee (Levee 1)

Details of the Commercial Road levee are provided in a range of design plans dated 22/10/90. The spatial coverage of the Commercial Road levee design plans is shown in **Figure 2**.

The levee was originally constructed in the 1970s and was subsequently raised in 1990. The levee comprises a grassed earthen embankment to the south of Murwillumbah that typically runs in an east-west direction towards Commercial Road. As shown in **Figure 4.1**, the crest elevation along this section of the levee varies between 7.5 mAHD (western end) and 7.3 mAHD (Commercial Road end). **Plate 1** provides a photo of this section of levee.

The second section of the levee is located on the eastern side of Commercial Road and runs in a north-south direction from the grassed embankment levee (in the south) towards the Wollumbin Street Bridge (in the north). This section of levee comprises a concrete panel wall system with gated "openings" that can be manually closed during floods (refer **Plate 2**). The wall is over 2 metres high along much of its length and the crest elevation varies between 7.3 mAHD (southern end) and 6.8mAHD (near Wollumbin Street Bridge). The concrete panel wall resumes on the northern side of the Wollumbin Street Bridge where it continues in a north-easterly direction before "tying in" with higher ground near the Murwillumbah YHA (located at around 6.6 mAHD).

Plate 1 View looking west from Commercial Road showing earthen embankment section of Commercial Road levee

Plate 2 View looking west towards Murwillumbah Services Club showing concrete panel section of the Commercial Road levee with gated openings

The *'Tweed Valley Flood Study'* (BMT WBM, 2009) estimates that the Commercial Road levee will afford protection from floods during events up to and including the 1 in 80 year ARI event.

Runoff from the catchment contained behind the levee is conveyed into the Tweed River via a series of pipes with flood gates. Further information on the drainage system is provided in Section 2.5.

2.4.2 East Murwillumbah Levee (Levee 2)

The details of the East Murwillumbah Levee are contained within a series of design plans titled "Murwillumbah Flood Levee Capping" dated 11/05/05. The extent of the area covered by the design plans is shown in **Figure 2**.

The original levee was constructed in 1976 and was subsequently raised in 2006. The levee generally consists of an earthen embankment that encircles East Murwillumbah. However, the south-western section of the levee (running parallel with Tumbulgum Road) comprises a concrete wall (refer **Plate 3**). As shown in **Figure 4.2**, the crest of the levee is typically located at an elevation of between 5.9 mAHD (south-western end) and 5.2 mAHD (north-western end). However, the crest elevation drops below 5.1 mAHD near the Murwillumbah East Primary School.

Plate 3 View looking north-east along concrete wall section of the East Murwillumbah levee

The plans also show that runoff from the local catchment is conveyed beneath the levee to the Tweed River or Myall Creek via a number of pipes. The pipes include:

- Twin 1.2m diameter pipes beneath George Street;
- 0.9m, 0.9m and 0.75m diameter pipes between the Tumbulgum Rd bridge crossing of Mayal Creek and Murwillumbah East Primary School;
- Two 0.45m diameter pipes on either side of the approach to the Tumbulgum Road bridge crossing of Mayal Creek;
- A 0.6m diameter pipe that runs beneath 19 Tumbulgum Road; and,
- A range of smaller 0.225m diameter pipes that collect local runoff from the rear of properties fronting Tumbulgum Road.

The downstream side of all pipes are protected by flood gates.

The *'Tweed Valley Flood Study'* (BMT WBM, 2009) estimates that the East Murwillumbah levee will afford protection from floods during events up to and including the 1 in 80 year ARI event.

2.4.3 Dorothy Street / Brothers Levee (Levee 3)

The Dorothy Street Levee (also referred to as the Brothers Levee) provides protection from Rous River flooding across West Murwillumbah. The alignment of the Dorothy Street Levee is shown in **Figure 1**.

The levee was constructed in 2006 and the details of the levee are contained in design plans titled "Dorothy Street Flood Levee Capping" dated 11/10/05. The extent of the area covered by the plans is shown in **Figure 2**. The plans show that the levee comprises a grassed earthen embankment that runs in an east-west direction. As shown in **Figure 4.3**, the crest of the levee is located at an elevation of 4.9mAHD.

The plans also show that runoff from the catchment contained behind the levee is drained by an open channel that discharges into a 3.6m x 2.1m reinforced concrete box culvert that carries runoff beneath the levee towards the Rous River (refer **Figure 4.3**). The downstream (i.e., northern) end of the culvert is fitted with an aluminium flood gate to prevent backwater inundation from the Rous River.

The *'Tweed Valley Flood Study'* (BMT WBM, 2009) estimates that the Dorothy Street levee will afford protection from floods in excess of the 1 in 100 year ARI event.

2.5 Local Drainage System

The areas behind each of the three levees are drained by a series of swales, kerb and gutter, stormwater pits and pipes, culverts and open channels/creeks. The extent of the local drainage system is defined in a variety of GIS layers as well as work-as-executed survey plans provided by Council. The extent of each drainage dataset is shown in **Figure 2**.

A review of the stormwater pit/pipe GIS layers determined that not all information required to define the conveyance characteristics of the stormwater system was available. In particular, over 30% of the pipes had no diameters defined and there was no information describing pipe/pit invert elevations. Therefore, Council collected additional pipe diameter and pit depth information at selected locations across Murwillumbah. Pipe diameters and pit invert elevations that were not collected by Council were estimated using the following approach:

- Where pipe diameter information was not available, the diameter was interpolated based upon inspection of the upstream and downstream pipe diameters and selecting the closest diameter from a table of standard pipe sizes. The adopted pipe diameters are illustrated in **Figures 4.1** to **4.3**.
- All stormwater pits without a type classification were assumed to comprise a grated kerb inlet with a lintel length of 1.2 metres.

- Across the steeper sections of Murwillumbah, the pit inverts were estimated using the following equation:
  -> *Invert elevation = Ground elevation – 1 metre*
- Across the flatter sections of Murwillumbah, the pit inverts were interpolated linearly. Some manual adjustments were completed by hand to ensure that there were no adverse pipe slopes.

Therefore, it should be noted that the representation of the drainage system is an approximation across some areas. However, across the flatter areas that are the focus of this study, a greater level of confidence is available with the stormwater system being defined based on work-as-executed survey plans or field measurements.

The stormwater pipes and culverts shown in **Figures 4.1** to **4.3** ultimately drain runoff towards the Tweed River, Rous River or Mayal Creek. As discussed in Section 2.4, the downstream end of each major pipe/culvert that drains beneath the levee system is protected by a flood gate which prevents elevated water levels from "backing up" the pipe/culvert system and inundating areas behind the levee (refer **Plate 4**). The location of flood gates is shown in **Figures 4.1** to **4.3**.

Plate 4 View showing flood gates on Tweed River side of Commercial Road culverts. The gates prevent water from the Tweed River "backing up" the culverts and inundating areas behind the levee

Council typically has sufficient warning time during Tweed River floods to check all flood gates to ensure they are operating as intended (e.g., removing any debris that may cause the gates to remain "open").

Although the flood gates do assist in preventing backwater inundation, they remain "closed" when there are elevated water levels within the Tweed and/or Rous Rivers which can hinder drainage. However, there are two pump systems that assist in draining the Murwillumbah CBD when there are elevated water levels within the Tweed River. Further information on the pump system is provided below.

2.6 Pump System

There are two Council operated flood pumping stations within Murwillumbah to assist in draining the Murwillumbah CBD. The pumps are designed to pump local runoff to the Tweed River when the floodgates prevent the stormwater system from draining under gravity to the Tweed River in times of flood. The main pump is located near the Lavender Creek crossing of Commercial Road and is referred to as the Lavender Creek Flood Pump Station 1 (FPS1). The second pump is a smaller system located within Wharf Park near its intersection with Tumbulgum Road (referred to as FPS2). The location of both pumping stations is shown in **Figure 4.1**.

2.6.1 Lavender Creek Flood Pump Station 1 (FPS1)

The Lavender Creek pumping station includes two separate pumps that operate in tandem (i.e., no backup pumps are provided). Each pump extracts water from upstream of Commercial Road via vertical intake structures (refer **Plate 5**) that carry the flow above the normal low flow pipes outlets and discharge into the Tweed River. The pipe outlets have flood gates fitted to prevent "backwater" inundation when there are elevated water levels in the Tweed River (refer **Plate 4**).

Plate 5 Lavender Creek Flood Pump Station 1 showing vertical intake structures (black vertical structures) and water level sensor (concrete chamber between the black intakes)

Each pump is activated once the water level exceeds "trigger" values within the water level sensor chamber (refer **Plate 5**). The pumps are initially activated at 70% of total capacity once the water level is approximately half way up the water level sensor chamber (refer marking circled in yellow in **Plate 5**). The capacity of the pump gradually increases to 100% when the water level reaches 0.1 metres from the top of the sensor chamber (refer marking circled in red in **Plate 5**).

Pump curves for FPS1 are provided in **Appendix A**. They show that each pump has a maximum capacity of 695 litres per second (i.e., 0.695 m^3/s). Therefore, the maximum flow capacity of FPS1 is approximately 1.4 m^3/s. The pump curves also show that as the required "head" increases (e.g., if water levels within the Tweed River start to rise above the outlet pipe), the available flow capacity reduces.

As discussed, there is currently no "backup" if the individual pumps malfunction during a flood event. Flooding during the January 2013 flood, for example, was exacerbated by the failure of a control panel in FPS1.

2.6.2 Wharf Street Flood Pump Station 2 (FPS2)

A smaller pump system is located near the intersection of Tumbulgum Road and Wharf Street. It is referred to as flood pump station 2 (FPS2).

Plans for FPS2 are included in **Appendix A**. The plans show a 3.3 metre deep manhole that is primarily serviced by a 450mm diameter pipe that carries runoff from the local stormwater system into the Tweed River during frequent rainfall events (this outlet is protected by a flood gate). However, once the water level in the manhole exceeds an elevation of 3.315 mAHD (i.e., during more significant rainfall events) flow is diverted from the manhole via a 450mm pipe into a 2.5m x 2.8m storage tank (providing 21 m^3/s of storage volume) which, in turn, drains by gravity into a separate sump/pit containing the pump. The pump is activated once the water level in the pit exceeds 3.76mAHD and ceases to operate once the water level in the pit drops below 2.8 mAHD. The pump discharges into the Tweed River via a high level 300mm diameter pipe that is protected by a flood gate.

No pump curve information is available for FPS2, but discussions with Council staff indicates that the capacity of this pump is considerably lower that the FPS1. For the purposes of this assessment, it was assumed that the capacity of FPS2 was equal to one third of the capacity of one of the FPS1 pumps (i.e., peak flow capacity of ~0.2 m^3/s).

Conversations with Council indicate that FPS2 has performed satisfactorily during all events since the pump was installed (circa 1991) with the exception of ex-Tropical Cyclone Debbie in March 2017. During this event, the capacity of the pump was exceeded resulting in above floor flooding of a number of businesses in Wharf Street / Murwillumbah Street. Further discussion on the March 2017 flood is provided in Section 2.7.

2.7 Historic Flood Information

Murwillumbah has a long history of flooding with major Tweed River floods inundating the CBD in 1954 and 1974. More recently, ex-Tropical Cyclone Debbie caused widespread flooding across the Tweed River Valley including Murwillumbah at the end of March 2017. Further information on this flood is provided in Section 2.7.1.

Tweed Shire Council provided flood marks and photographs from events that occurred in 2012 and 2016 in addition to March 2017 to assist with the study. This information included:

- 2012 Flood: 10 flood marks.
- 2016 Flood: 7 flood marks
- 2017 Flood: 78 flood marks

The flood marks provide peak water levels at discreet locations across the CBD for each event (the 2017 flood marks also provide flood elevations elsewhere across the Tweed River and Rous River floodplains). In addition to providing valuable information that assisted with the calibration of the computer flood model, the distribution of flood marks also shows where flooding was experienced during these past events (i.e., highlights flooding/drainage "trouble spots").

A selection of historic flood photographs for the 2008, 2012, 2013 and 2014 floods are provided in **Appendix A**. The photographs typically show water "ponding" at localised low points throughout the CBD. Knox Park and the sporting fields towards the south of the township feature prominently in the photographs indicating particularly problematic areas from a flooding perspective.

2.7.1 Ex-Tropical Cyclone Debbie

Ex-tropical Cyclone Debbie, which originally made land-fall north of Mackay in Queensland as a category 4 system, caused widespread flooding across the Tweed River Valley over the 30th and 31st of March 2017. The flood is the largest to be recorded at Murwillumbah since records commenced.

Tweed Shire Council prepared a report summarising the March 2017 event and a copy of this report is enclosed in **Appendix D**. The report discusses the flood impacts across the broader Tweed LGA with a particular focus on the impacts to public assets and services. Nevertheless, the report does provide some detailed observations on flooding in the vicinity of Murwillumbah during this event. This includes:

- The earthen section of the Commercial Road levee was overtopped at two locations (south of Les Cave Oval and south of the Murwillumbah High School). The concrete wall sections of the Commercial Road levee were not overtopped.
- The Murwillumbah East levee experienced minor overtopping near the Murwillumbah East Primary School.
- The Dorothy Street Levee was overtopped by approximately 300 mm. Significant local catchment flooding was also experienced behind the levee with the Brothers Leagues club as well as several properties in William Street suffering inundation.
- The Wharf Street pump station operated throughout the event. However, the capacity of the pump was exceeded resulting in above floor inundation of a number of commercial properties.
- The Lavender Creek pump station operated through most of the event. However, the pump station lost power for a short period in the early hours of the morning on 31st March (just after the flood peaked). As with the Wharf Road pump, the capacity of the Lavender Creek pump station appears to have been overwhelmed during the event.

- Significant flooding behind the Commercial Road levee was experienced resulting in inundation of homes and businesses in Main Street, Commercial Road, Brisbane Street, Wollumbin Street, Nullum Street and Condong Street.
- The flood is considered to be approximately equal to a 1% AEP flood for the Tweed River at Murwillumbah and is thought to have exceeded the 1% AEP flood for the Rous River at Murwillumbah.

A selection of photographs of the 2017 flood at various locations are provided in **Appendix D**. It should be noted that not all photographs were taken at the peak of the flood (the flood peaked at approximately 1am on the 31st March). Therefore, the extent and depth of inundation at the peak of the flood was typically more extensive than that depicted in most photos that were taken the following morning and afternoon.

2.8 Community Consultation

A community questionnaire was prepared and distributed to approximately 877 residential and business properties within the study area. A copy of the questionnaire is included in **Appendix J**.

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 116 questionnaire responses were received and a summary of all questionnaire responses is provided in **Appendix J**. Most of the responses included addresses enabling spatial interpretation of the questionnaire responses (refer **Figure J1**).

The responses to the questionnaire indicate that:

- Over 80% of respondents have experienced some form of inundation or disruption as a result of flooding (refer **Figure J1**). This includes:
  -> Traffic disruptions (51 respondents);
  -> Inundation of garage & shed (46 respondents); and,
  -> House or business inundated above floor level (22 respondents).
- The population has a mixed level of flood awareness. Of those who answered question 5, 19% of respondents admitted that they did not know whether their house or business was potentially flood liable or not. However, of the 27 who claimed to know that their house or business could *not* be flooded, 63% are located within the PMF extent (only 1 was within the 1% AEP extent).
- People's understanding of flood risks can also be assessed through answers to question 6 and GIS analysis. About 85% of those who believed their house or business could be flooded in the PMF event were correct.
- Questions 7-9 were designed to gain an understanding of people's likely behaviours during future flood emergencies. It was found that 57% of respondents indicated they would remain at home and only 16% indicated they would evacuate to an official evacuation centre. For those respondents that indicated they would remain at home, 5 are located on the eastern side of Knox Park and may be isolated prior to the levee overtopping (refer Section 5.3.2 for further details).
- In order of priority, the reasons for remaining at home were:

    - residents felt confident that their home could not be flooded and they could cope with temporary isolation;
    - concern about security of an evacuated property;
    - a need to care for animals; and,
    - the discomfort/inconvenience/cost of evacuating.
- For those intending to evacuate, safety of their family was the overriding concern.
- About 10% of respondents indicated that they did not know how they would react during a future flood.

The questionnaire also sought feedback on a preliminary list of flood risk management measures that were under consideration as part of the study. Further discussion on the community feedback on each option is presented in Section 6.

3 Computer Flood Model

3.1 General

Design flood characteristics across the Tweed River catchment is currently defined using a WBNM hydrologic model and a TUFLOW hydraulic model that was developed as part of the "Tweed Valley Flood Study" (BMT WBM, 2009). Both models were reviewed as part of the current study and were found to be suitable for defining broad-scale flood behaviour. However, as noted in Section 2.2.1, the relatively large grid size employed in the TUFLOW model means that it does not provide a detailed understanding of the local movement of floodwaters across Murwillumbah (from local catchment runoff as well as from overtopping of the levee) and a more detailed model is necessary to reliably reflect the movement of water along roadways and around buildings.

The following chapter provides an overview of the development of the more detailed hydraulic model.

3.2 Hydrologic Model Updates

3.2.1 Additional Subcatchments

Inflows to the TUFLOW hydraulic model were defined using flow hydrographs generated by a WBNM hydrologic model of the Tweed River catchment. The Tweed River catchment was subdivided into 207 subcatchments to define the spatial variation in hydrologic properties in the WBNM model. In general, this level of discretisation is suitable for describing broad scale inflows along each of the major watercourses in the Tweed River catchment.

However, in the immediate vicinity of Murwillumbah, the subcatchment delineation does not differentiate between the section of the subcatchment located behind the Murwillumbah levees and that section of the subcatchment draining directly to the river system (i.e., it assumes all runoff from Murwillumbah is distributed directly to the rivers). An important component of the current study was to define drainage conditions behind the levee system. Therefore, it was necessary to subdivide each subcatchment in the vicinity of Murwillumbah to enable runoff generated from behind the level to be quantified. In this regard, two additional subcatchments were included in the WBNM model (refer **Plate 6**).

3.3 Hydraulic Model Development

3.3.1 Model Extent and Grid Size

As discussed, it was necessary to develop a more detailed hydraulic model of the study area to meet the objectives of the study. In this regard, the original 40-metre grid size was reduced to a 5-metre grid size to allow a more detailed representation of topography, hydraulic resistance and urban flow impediments in the vicinity of Murwillumbah.

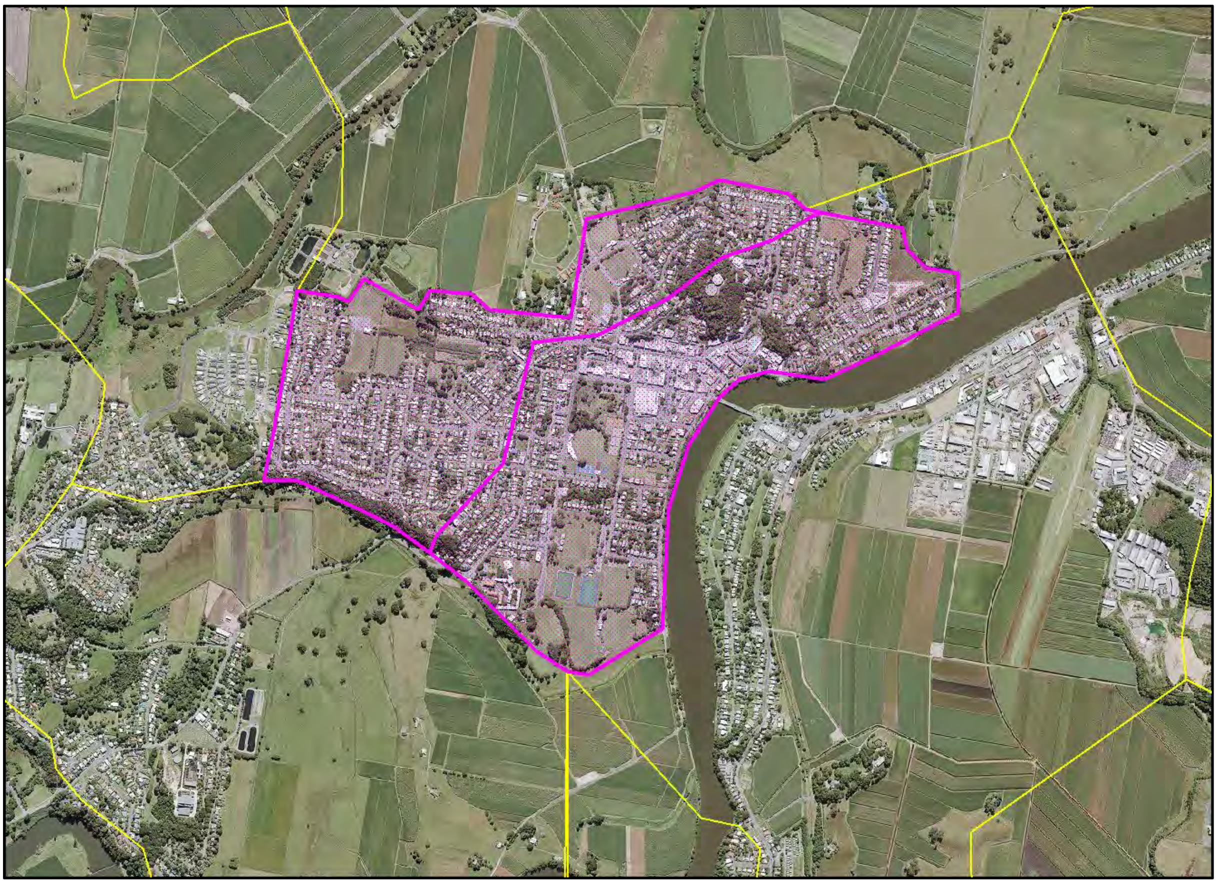


Plate 6 Original WBNM subcatchment boundaries (yellow) with new WBNM subcatchments covering Murwillumbah (purple)

However, to keep the model run times within reasonable limits, it was also necessary to reduce the geographic area covered by the model. Therefore, the model extent was reduced to only cover that sections of the Tweed and Rous River floodplains surrounding Murwillumbah. The extent of the modified model is shown in **Figure 6**.

3.3.2 Material Types & Manning's "n"

The TUFLOW software uses land use information to define the hydraulic properties for each grid cell in the model (e.g., hydraulic roughness coefficients). The original model employed large scale polygons to define the variation in hydraulic properties across the model. For example, the township of Murwillumbah was delineated as a single "urban" land use type. This broad-scale delineation fails to account for the different hydraulic resistance afforded by different land uses across the township including roadways, grass, trees and buildings.

Therefore, a more detailed approach to land use delineation was employed across Murwillumbah. This approach took advantage of the 2014 LiDAR which includes information on non-ground points (e.g., buildings, trees) as well as other information including point intensity and multiple return information. This information can be used with aerial photography to assist with the identification of different land uses across the catchment. This, in turn, can be used to assist in defining the spatial variation in land uses across the catchment which can inform Manning's 'n' roughness coefficients and rainfall losses in the computer flood model.

This technique of land use classification was based on research documented in a paper prepared by Ryan titled *'Using LiDAR Survey for Land Use Classification'* (2013) and was applied to Murwillumbah based upon the 2014 LiDAR and 2015 aerial imagery. The classification algorithm divided the study area into the following land use classifications:

- Buildings
- Water
- Trees
- Grass
- Impervious (concrete and roads)

It should be noted that perfect accuracy cannot be expected from any automated classification, particularly when the LiDAR and aerial imagery date from different periods (i.e., 2011 & 2014). Errors can also arise due to shadowing effects. As a result, manual updates to the remote sensing outputs was completed to ensure a reliable representation of the spatial variation in land use was provided across the catchment.

The final remote sensing output is shown in **Figure 5**.

Due to the increased level of detail afforded by the remote sensing, it was necessary to define additional roughness coefficients. The new land uses and the roughness coefficients are summarised in **Table 1**.

Table 1 Additional Material Types

Land Use Description	Manning's 'n' Value
Impervious (concrete, roads)	0.015
Grass	0.035
Trees	0.100
Water	0.025
Buildings	2.000

In areas outside of Murwillumbah, the land use polygons and Manning's "n" values from the original TUFLOW model were retained.

3.3.3 Stormwater System

The stormwater system has the potential to convey a significant proportion of runoff across the Murwillumbah CBD during frequent rainfall events. Therefore, it was considered important to incorporate the stormwater system in the TUFLOW model to ensure the interaction between piped stormwater and overland flows was reliably represented.

The full stormwater system contained within the catchment was included within the TUFLOW model as a dynamically linked 1-Dimensional (1D) network. This allowed representation of the conveyance of flows by the stormwater system below ground as well as simulation of overland flows in two dimensions once the capacity of the stormwater system is exceeded.

As discussed in Section 2.5, the stormwater network details were extracted from a Council GIS layer. Each stormwater pit was allocated a pit type based on available information for the pit. Once all stormwater pit types were defined across the catchment, inlet capacity curves were prepared to define the variation in pit inflow capacity with respect to water depth at each pit location. The 'Drains Generic Pit Spreadsheet' (Watercom Pty Ltd, July 2005), was used to develop the inlet capacity curves. The inlet capacity curves were developed to take account of:

- The different pit inlet types (e.g., grated, side entry, combination)
- The size of the inlet (e.g., lintel size, grate size)
- The different topographic locations (e.g., sag or on-grade)

Hydraulic 'losses' throughout the stormwater system were estimated using the Engelhund loss approach (BMT WBM, 2015). This loss approach automatically accounts for the following loss components at each stormwater pit for each model time step:

- Pit entrance loss
- Loss associated with a drop in elevation between inlet and outlet pipes
- Loss associated with a change in flow direction between the inlet and output pipes
- Pit exit loss

The extent of the stormwater system included within the TUFLOW model is shown in **Figure 6.**

Those pipes and culverts that include a flood gate were represented as a unidirectional flow structure in TUFLOW. This allows water to flow along the pipe/culvert in one direction only, thereby, preventing water from "backing up" the drainage system from the river.

Stormwater Blockage

There is potential for blockage of stormwater inlets/pits to occur during storms (refer **Plate 7**). Accordingly, blockage factors were assigned to all stormwater pits to reflect the reduced inflow capacity that would occur with partial pit blockage.

Plate 7 View showing partial blockage of a stormwater pit near Knox Park

The following blockage factors were applied to the stormwater pits:

- 50% blockage for all pits located in sag locations; and,
- 20% blockage for on-grade pits.

3.3.4 Pumps

The two flood pump stations described in Section 2.6 were also included within the TUFLOW model as "operationally controlled" hydraulic structures. This allows a unique pump discharge-head curve to be defined for each pump station along with operational controls describing when the pumps turn on and off. The operational controls of each pump that were described in Section 2.6 were also replicated in the TUFLOW model.

4 Computer Model Calibration

4.1 Overview

Computer flood models are approximations of a very complex process and are generally developed using parameters that are not always known with a high degree of certainty and/or are subject to natural variability. This includes catchment roughness and vegetation density as well as blockage of hydraulic structures. Accordingly, the model should be calibrated using rainfall, flow and flood mark information from historic floods to ensure the adopted model parameters are producing reliable estimates of flood behaviour.

Calibration is typically completed by routing recorded rainfall from historic floods through the computer model. Simulated flows and flood levels are extracted from the model results at locations where recorded data are available. Calibration is completed by iteratively adjusting the model parameters within reasonable bounds to achieve the best possible match between simulated and recorded flood flows and flood levels.

As outlined in Section 2.7, a number of flood marks were surveyed across Murwillumbah following past floods including:

- January 2012;
- June 2016; and,
- March 2017.

In addition, a significant amount of historic rainfall information is available as well as stream gauging information. This was considered a sufficient amount of information to procced with the calibration of the TUFLOW model. The outcomes of the calibration are presented in the following sections.

It was noted that a satisfactory calibration of the WBNM model was completed as part of the *'Tweed Valley Flood Study'* (BMT WMB, 2009). As the model remains largely unchanged as part of the current study, re-calibration of the WBNM model was not attempted.

4.2 March 2017 Flood

4.2.1 Rainfall

A detailed description of the March 2017 (i.e., ex-Tropical Cyclone Debbie) flood is provided in Section 2.7.1 as well as **Appendix D**.

Accumulated rainfall totals for each rainfall gauge that was operational during the 2016 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 7**. **Figure 7** shows that in excess of 750 mm of rain fell over a 24 hour period across some parts of the upper catchment during the 2017 event. **Figure 7** also shows significant spatial variation in rainfall across the catchment with rainfall depths across the coastal areas being less than half of rainfall depths across the upper catchment areas. Due to the significant spatial variation in rainfall during this event the isohyet map shown in **Figure 7** was used to describe the spatial variation in rainfall within the WBNM model.

A pluviograph for the Murwillumbah rain gauge (Gauge #7152) is presented in **Appendix C** for the 2017 event (refer **Figure C2**). The continuous rainfall information for Gauge #7152 was also analysed relative to design rainfall-intensity-duration information for the catchment. This information is presented in **Appendix C** as **Figure C5** and indicates that the 2017 rainfall intensity was slightly less than that of a 1% AEP design event at Murwillumbah (however, it is acknowledged that across part sections of upper Tweed River catchment that rainfalls in excess of the 1% AEP event were likely experienced).

4.2.2 Downstream Boundary Conditions

Hydraulic computer models also require the adoption of a suitable downstream boundary condition in order to reliably define flood behaviour throughout the area of interest. The downstream boundary condition is typically defined as a known water surface elevation (i.e., stage).

The downstream boundary of the computer model is located approximately one third of the way between Murwillumbah and Tumbulgum. Unfortunately, there are no stream gauges located in the immediate vicinity of the downstream boundary of the TUFLOW model to assist in defining water levels for the 2017 event at this location. However, there are stream gauges that were active during the 2017 flood at Murwillumbah and Tumbulgum. In addition, several surveyed flood marks are available in the vicinity of the downstream boundary indicating the peak water level along this boundary. Therefore, the variation in water level at the downstream model boundary was defined by interpolating the water level observations at the Murwillumbah and Tumbulgum gauges until the historic flood mark elevations at the downstream boundary were replicated. This yielded a weighting of 45% to the Murwillumbah gauge and 55% to the Tumbulgum gauge.

4.2.3 Results

Calibration of the TUFLOW hydraulic model was attempted using 78 surveyed flood marks as well as recorded stage hydrographs for the 2017 event. The calibration was undertaken by routing the discharge hydrographs generated by the WBNM model for the 2017 event through the TUFLOW model and comparing reported and simulated flood levels at each flood mark location.

Peak floodwater depths were extracted from the results of the 2017 flood simulation and are included on **Figure 8**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood mark elevations is also provided in **Figure 8**. The flood level comparison is also tabulated in **Appendix E**.

The flood level comparison provided in **Figure 8** and **Appendix E** shows that the 2017 flood mark elevations are generally well reproduced by the TUFLOW model. The average difference between simulated flood levels and surveyed flood mark elevations is 0.03 metres. There are some bigger differences at isolated locations, but this appears to be associated with flood mark discrepancies (i.e., flood mark elevations that differ significantly from nearby flood mark elevations). For example, a surveyed flood mark elevation across the Elizabeth Street sporting fields of 2.47 mAHD is over 1 metre lower than all other flood mark behind the Commercial Road level (3.8 mAHD), which are all reproduced well by the TUFLOW model. But overall, it is considered that the flood mark comparisons show that flood and drainage behaviour behind the Murwillumbah levee system is being well reproduced by the TUFLOW model for the 2017 event.

The time variation in simulated flood water levels were also extracted at the location of the Tweed River at Murwillumbah and the Tweed River at Murwillumbah Bridge stream gauges and are shown in **Figures 9.1** and **9.2**. The recorded stage hydrographs at each stream gauge were also extracted and are included on **Figures 9.1** and **9.2** for comparison.

Figures 9.1 and **9.2** shows that TUFLOW model provides a good reproduction of the overall shape of the recorded stage hydrographs at Murwillumbah North and Murwillumbah Bridge. More specifically, the timing and magnitude of the peak stages are well reproduced by the TUFLOW model. This confirms than mainstream flood behaviour is being well reproduced by the model.

Figure 8 also shows water spilling across the Commercial Road earthen levee south of the Elizabeth Street sporting fields, which was observed during the 2017 event. **Figure 8** also shows water overtopping the Dorothy Street levee which was also observed. This provides further confidence that the model is providing a reasonable reproduction of mainstream flood behaviour as well as the potential for levee overtopping.

Overall, it is considered that the TUFLOW model is providing a good reproduction of flood observations and post-flood data collection from the 2017 event.

4.3 January 2012 Flood

4.3.1 Rainfall

The 2012 flood was produced by an extended period of rain falling between the 23rd and 26th January. Accumulated rainfall totals for each rain gauge that was operational during the 2012 event were used to develop a rainfall isohyet map for the Tweed River catchment, which is shown in **Figure 10**. The isohyet map describes how the rainfall varied spatially across the catchment and was used as the basis for describing the spatial variation in rainfall in the WBNM model for the 2012 event. The rainfall isohyet map was also statistically analysed and this determined that the average rainfall depth across the catchment during this event was 368 mm.

A pluviograph for the Murwillumbah rain gauge (Gauge #7152) is presented in **Appendix C** for the 2012 event (refer **Figure C3**). It shows that the most intense period of rainfall occurred on the 26th and 27th of January where over 300 mm of rain fell in the immediate vicinity of Murwillumbah.

The continuous rainfall information for Gauge #7152 was also analysed relative to design rainfall-intensity-duration information for the catchment. This information is presented in **Appendix C** as **Figure C5** and indicates that, based on the available rainfall records, the 2012 event was slightly more severe than a 20% AEP flood event across the Murwillumbah CBD catchment.

4.3.2 Downstream Boundary Conditions

As with the 2017 flood simulation, the downstream boundary condition was defined as a stage hydrograph. The stage hydrograph was developed by interpolating between the recorded stage hydrographs at the Murwillumbah Bridge and Tumbulgum stream gauges. The same weighting that was applied to the recorded stage hydrographs for the 2017 event was also applied for the 2012 event (i.e., 45% to the Murwillumbah Gauge and 55% to the Tumbulgum gauge).

4.3.3 Modifications to Represent Historic Conditions

A review of aerial imagery from 2012 and 2016 indicates that there have been minimal changes in land use and topography across Murwillumbah since the 2012 flood. Therefore, no updates to the 2016 version of the TUFLOW model were completed to reflect 2012 conditions.

4.3.4 Results

Calibration of the TUFLOW hydraulic model was attempted using 10 surveyed flood marks as well as recorded stage hydrographs for the 2012 event. The calibration was undertaken by routing the discharge hydrographs generated by the WBNM model for the 2012 event through the TUFLOW model and adjusting roughness parameter values until a reasonable agreement between simulated flood levels to the recorded flood marks was achieved.

Peak floodwater depths were extracted from the results of the 2012 flood simulation and are included on **Figure 11**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood mark elevations is also provided in **Figure 11**. The flood level comparison is also tabulated in **Appendix E**.

The flood level comparison provided in **Figure 11** and **Appendix E** shows that the TUFLOW model provides a good reproduction of the surveyed flood marks at most locations. In particular, the TUFLOW model reproduces the surveyed floods marks to within 0.12 metres at all but one location with an average difference of 0.08 metres. The TUFLOW model produces higher peak flood levels at all locations for the 2012 simulation.

The most significance difference between simulated flood levels and recorded flood marks is 0.25 metres and occurs along Proudfoot Lane. No reasonable explanation could be found for this isolated discrepancy as the flood mark elevations elsewhere along Proudfoot Lane are well reproduced by the TUFLOW model.

Overall, the flood mark comparison indicates that the TUFLOW model is providing a reasonable representation of flood behaviour behind the Commercial Road levee.

Simulated flood water levels were also extracted at the location of the Tweed River at Murwillumbah Bridge and South Murwillumbah stream gauges and are shown in **Figure 12**. The recorded stage hydrographs at each stream gauge was also extracted and are superimposed on **Figure 12** for comparison.

Figure 12 shows that TUFLOW model provides a good reproduction of the overall shape of the recorded stage hydrographs at South Murwillumbah and the Murwillumbah Bridge. In general, the timing and magnitude of the peak stages are well reproduced by the TUFLOW model. This indicates that mainstream flood behaviour is also being well reproduced by the TUFLOW model.

4.4 June 2016 Flood

4.4.1 Rainfall

The 2016 flood was generated by a downpour on the 3rd and 4th of June. Accumulated rainfall totals for each rainfall gauge that was operational during the 2016 event were used to develop a rainfall isohyet map for the event, which is shown in **Figure 13**. This isohyet map was used to describe the spatial variation in rainfall within the WBNM model. The isohyet map was also statistically analysed and this determined that the average rainfall depth across the catchment during the 2016 event was 305 mm.

A pluviograph for the Murwillumbah rain gauge (Gauge #7152) is presented in **Appendix C** for the 2016 event (refer **Figure C4**). It shows that that the main downpour occurred on the 4th June where over 200 mm of rain fell.

The continuous rainfall information for Gauge #7152 was also analysed relative to design rainfall-intensity-duration information for the catchment. This information is presented in **Appendix C** as **Figure C5** and indicates that the 2016 rainfall had an intensity that falls between a 50% AEP and 20% AEP event.

4.4.2 Downstream Boundary Conditions

As with the 2012 and 2017 flood simulations, the downstream boundary condition was defined as a stage hydrograph. The stage hydrograph was developed by interpolating between the recorded stage hydrographs at the Murwillumbah Bridge and Tumbulgum stream gauges.

4.4.3 Results

Calibration of the TUFLOW hydraulic model was attempted using 7 surveyed flood marks as well as recorded stage hydrographs for the 2016 event. All surveyed flood mark elevations were collected in the area behind the Commercial Road levee.

The calibration was undertaken by routing the discharge hydrographs generated by the WBNM model for the 2016 event through the TUFLOW model and comparing reported and simulated flood levels at each location.

Peak floodwater depths were extracted from the results of the 2016 flood simulation and are included on **Figure 14**. A comparison between the peak flood levels generated by the TUFLOW model and the surveyed flood mark elevations is also provided in **Figure 14**. The flood level comparison is also summarised in **Appendix E**.

The flood level comparison provided in **Figure 14** shows that the TUFLOW model provides a reasonable reproduction of the surveyed flood mark elevations for the 2016 flood. The TUFLOW model produces lower peak flood level estimates at all locations relative to the surveyed flood marks with the average difference being -0.09 metres.

In general, it is considered that the TUFLOW model is providing a reasonable replication of flood and drainage behaviour behind the Commercial Road levee.

In an effort to confirm mainstream flood behaviour was also being reproduced by the model, simulated and recorded stage hydrographs were extracted at the location of the South Murwillumbah and Murwillumbah Bridge gauges. This comparison is provided in **Figure 15**.

Figure 15 shows that TUFLOW model provides a good reproduction of the overall shape of the recorded stage hydrographs at Murwillumbah Bridge. More specifically, the timing and magnitude of the peak stages are well reproduced by the TUFLOW model. This confirms than mainstream flood behaviour is being well reproduced by the model.

5 Defining the Existing Flooding Problem

5.1 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).

The calibrated TUFLOW model that was documented in the previous chapter was used to simulate a range of design flood events for existing topographic and development conditions and generate range of flooding information (e.g., flood depths, levels and velocities). Further information on the design flood simulations and the associated model outputs are provided in the following sections.

5.2 Existing Flood Behaviour

The 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.

A range of design storm durations were analysed to determine the critical storm duration for the township. The critical duration was defined as the storm duration that produced the highest peak flood levels around Murwillumbah. This determined that the 36-hour storm was the critical storm duration for "mainstream" flooding as well as flooding behind each of the levees. Accordingly, the flood results documented in the following sections are based upon the 36-hour storm duration.

Design flow hydrographs (describing how the river discharges vary with respect to time) for the Tweed and Rous Rivers for the 36-hour storm duration are provided in **Figure 16**.

5.2.1 Floodwater Depths and Levels

Peak floodwater depths were extracted from the results of the design flood simulations and are presented in **Figures 17** to **20** for the 20%, 5%, 1% and 0.2% AEP events respectively.

Peak flood levels were also extracted from the results of the modelling and are presented in **Figures 21** to **24**. Peak water level profiles in the immediately vicinity of each levee were extracted for each design flood and are presented in **Figure 29**. The levee profiles are also included in **Figure 29**.

Figures 17 and **18** show that during events up to and including the 5% AEP flood, no overtopping of the levee system is predicted. However, **Figure 19** shows that during the 1%

AEP flood, the southern part of the Commercial Road levee (i.e., the earthen embankment) is predicted to overtop at two locations (although the overtopping depth is predicted to be less than 0.3 metres). This differs from the outcomes of the *'Tweed Valley Flood Study'* (BMT WBM, 2005) which indicated that overtopping of the Commercial Road levee would likely first occur near the bridge. It is considered that these differences are associated with:

- The new TUFLOW model providing a more detailed description of the variation in levee crest elevation. In particular, the new model takes advantage of more recent LiDAR information that provides a better description of the variation in elevation along the earthen embankment section of the levee (in particular, areas that appear to have "settled" from the original design elevations).
- The new model provides a more detailed description of flow "break outs" across South Murwillumbah. This allows a greater proportion of flow to discharge through South Murwillumbah leading to lower design flood levels along the Tweed River (including near the bridge).

Overtopping of the Dorothy Street and East Murwillumbah levees is not predicted during the 1% AEP event. However, **Figure 29** shows that less than 0.05 metres of freeboard would be available for the East Murwillumbah levee. Approximately 0.3 metres of freeboard is available at the Dorothy Street levee at the peak of the 1% AEP event.

Figure 20 and **Figure 29** shows that overtopping of all levees is anticipated during the 0.2% AEP event. **Figure 20** also shows that the area behind the Commercial Road levee will be subject to inundation depths of well over 2 metres. Accordingly, the impacts across the Murwillumbah CBD increase significantly between the 1% AEP flood (where only the southern section of the Commercial Road levee is overtopped by depths of less than 0.3 metres) and the 0.2% AEP flood (where almost the entire length of levee is overtopped by depths of over 0.5 metres).

Accordingly, the results of the modelling show that the following levels of protection are afforded by the existing levee system:

- Commercial Road Levee: <1% AEP event (but more than the 5% AEP flood)
- East Murwillumbah Levee: ~1%AEP flood
- Dorothy Street Levee: >1% AEP flood (but less than the 0.2% AEP flood)

5.2.2 Floodwater Velocities

Peak flow velocities were also extracted from the results of the modelling to illustrate the speed at which water moves through the area during each design flood. The velocity maps are presented in **Figures 25** to **28**.

The velocity maps show that during events up to and including the 1% AEP flood, low flow velocities are generally anticipated behind each of the levees (i.e., water is typically "ponding" behind each levee).

However, **Figure 28** shows that once significant overtopping of the Commercial Road levee occurs, some velocities of up to 1 m/s are anticipated as water overtops the southern part of the levee and moves north through the township. That is, during the 0.2% AEP flood, distinct flow paths through the town start to develop.

The area behind the Dorothy Street levee is not predicted to be exposed to significant flow velocities as this area is impacted by “backwater” inundation from the Rous River only. Localised sections of East Murwillumbah are predicted to be exposed to flow velocities of more than 0.5 m/s during the 0.2% AEP flood. However, this area is somewhat protected by the section of elevated land located in the vicinity of the Murwillumbah YHA.

5.2.3 Stormwater Capacity

The TUFLOW modelling also provided information describing the amount of water flowing into each stormwater pit and through each stormwater pipe. This includes information describing which pipes are flowing completely full during each design flood. This information can be used to provide an assessment of the capacity of each pit and pipe in the stormwater system. In doing so, it allows identification of where stormwater capacity constraints may exist across the study area.

The pipe flow results of all design flood simulations were interrogated to determine the capacity of each stormwater pipe in terms of a nominal exceedance probability (i.e., AEP). The capacity of the pipe was defined as the largest design event whereby the pipe was not flowing completely full. For example, if a particular stormwater pipe was flowing 95% full during the 20% AEP event and 100% full during the 5% AEP event, the pipe capacity would be defined as “20% AEP”.

A nominal exceedance probability was also calculated for each stormwater pit based on one of the following “failure” criteria:

- AEP at which the pit begins to surcharge;
- AEP at which the water depth at the pit exceeds 0.2 metres;

The resulting stormwater capacity maps are presented in **Figure 30**. As shown in **Figure 30**, the pit and pipe capacities are colour coded based on the nominal exceedance probability that was calculated. Furthermore, different symbols have been applied to each pit to define whether the pit first “fails” via ponding depth or surcharge.

The information presented in **Figure 30** shows that the majority of the stormwater system in the lower and flatter portion of the study area typically has a capacity of less than the 20% AEP (i.e., 1 in 5 year ARI). Accordingly, inundation behind the levee system (most notably the lower lying areas behind the Commercial Road levee) is predicted to occur relatively frequently as the stormwater system is unable to convey all surficial flows during relatively frequent events.

The capacity mapping also indicates that it is lack of pipe capacity rather than lack of pit capacity that is the major limitation in the drainage system (i.e., the pipes are generally predicted to fail before the pits). This is considered to be a function of the relatively flat pipe grades as well as elevated water levels in the main river system.

It should be noted that the drainage assessment assumes partial blockage of all stormwater pits, which may impact on the outcomes of the capacity assessment. However, as noted above, the pipe system is predicted to fail before the pits system even with partial blockage.

Therefore, it is considered that the pipe capacity mapping provides a reasonable understanding of the stormwater capacity constraints across the study area.

5.2.4 Flood Hazard Categories

Flood hazard defines the potential impact that flooding will have on development 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 8**. As shown in **Plate 8**, the hazard curves assess the potential vulnerability of people, cars and structures based upon the depth and velocity of floodwaters at a particular location.

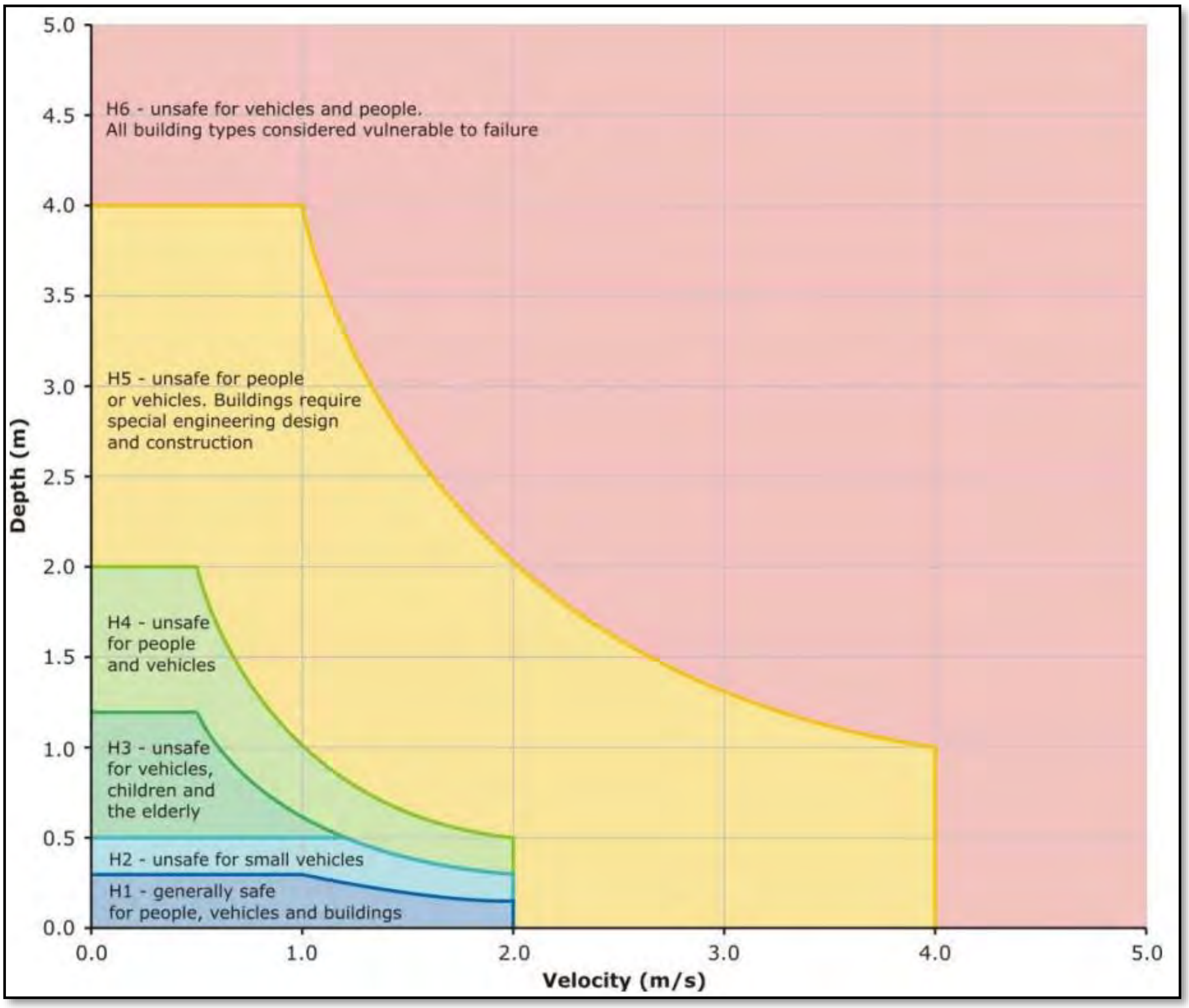


Plate 8 Flood hazard vulnerability curves (Australian Government, 2014)

Peak depth, velocity and velocity-depth product outputs generated by the TUFLOW model were used to map the variation in flood hazard across the Murwillumbah CBD Study Area based on the hazard criteria shown in **Plate 8** for the 1% and 0.2% AEP floods. The resulting hazard category maps are shown in **Figure 31** and **Figure 32**.

Figure 31 shows that most areas contained behind the levee system would be exposed to a hazard category of H3 or below during the 1% AEP flood. This indicates that during a 1% AEP flood, damage to property is unlikely and adults should be able to wade through water to higher ground. However, it would not be possible to drive through some areas and children and the elderly may be unable to wade to safety if they do not evacuate early.

Figure 32 shows a significant increase in flood hazard behind the levee system is predicted if a 0.2% AEP flood was to occur. In particular, a significant area behind the Commercial Road levee is predicted to be exposed to a H6 category indicating it would be unsafe for all people and there is potential for structural damage to buildings. Accordingly, the flood risk is predicted to increase significantly behind the Commercial Road levee once floods in excess of 1% AEP occur. The increase in flood hazard is not as significant across East Murwillumbah or behind the Dorothy Street Levee. Nevertheless, some significant H5 areas are predicted indicating hazardous conditions would still occur.

5.2.5 Hydraulic Categories

The NSW Government's *'Floodplain Development Manual'* (NSW Government, 2005) recommends subdividing flood prone areas into three separate hydraulic categories (refer **Table 2**). The hydraulic categories provide an indication of the potential for development across different sections of the floodplain to impact on existing flood behaviour (i.e., flood storage areas) and highlights areas that should be retained for the conveyance of floodwaters (i.e., floodways).

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 2** and were retained as part of the current study.

The hydraulic category maps that were developed based upon the criteria listed in **Table 2** for the 1% and 0.2% AEP floods are shown in **Figure 33** and **Figure 34**.

Figure 33 shows that during the 1% AEP flood, those areas subject to inundation behind each levee would be classified as either flood storage or flood fringe. However, **Figure 34** shows that during the 0.2% AEP flood, significant sections of the township behind the Commercial Road levee would be considered floodways.

5.2.6 Emergency Response Precinct Classifications

In an effort to understand the potential emergency response requirements across different sections of Murwillumbah, flood emergency response precinct (ERP) classifications were prepared in accordance with the flow chart shown in **Plate 9** (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.

Table 2 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
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 metres 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

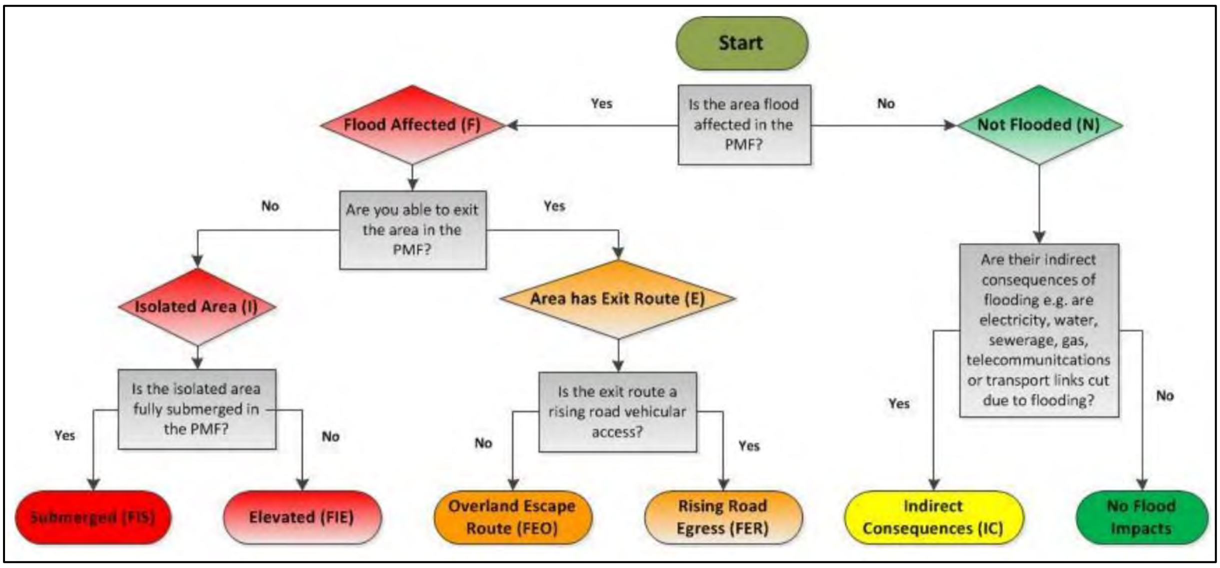


Plate 9 Flow Chart for Determining Emergency Response Planning Classifications (AEMI, 2014).

Each allotment within the 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 0.2m depth threshold was used to define a "cut" road); and,
- whether evacuation routes continuously rise out of the floodplain.

The resulting ERP classifications for the 1% and 0.2% AEP floods are provided in **Figure 35** and **Figure 36**. 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 5.3.2**.

Figure 35 shows that a number of properties located behind the Commercial Road levee are predicted to be isolated during the 1% AEP flood. The majority of these properties would not experience above floor inundation. However, during the 0.2% AEP flood, the vast majority of properties behind the Commercial Road and East Murwillumbah Levees would be inundated. This indicates that if a large flood was to occur and evacuation did not commence early, a large number of properties would be exposed to a significant flood risk and it is unlikely that emergency services would be able to support all of these properties. It highlights that early evacuation from areas located behind the Commercial Road and East Murwillumbah levee is critical for minimising the risk to life during large floods that overtop the levee system.

5.2.7 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 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 37**.

5.2.8 Time of Inundation

A key consideration when quantifying the potential flood risk across Murwillumbah is how much warning time would be available before levees overtopping commences and how long it will take for water levels behind the levee to rise. The time that it takes for water to drain from behind the levees is also an important consideration as it dictates when recovery efforts can commence. In this regard, levee overtopping times were extracted from the results of the modelling and are presented in **Table 3**, **Table 4** and **Table 5** for the Commercial Road, East Murwillumbah and Dorothy Street levees respectively. All times are stated relative to the start of rainfall.

The time that it takes for water levels behind the levee to peak was also extracted from the modelling results to assist in quantifying how long it will take to "fill" the area behind the levee once overtopping of the levee commences. In addition, the amount of time it takes for water in the area behind the levee to drain/empty was also extracted and is presented in **Table 3**, **Table 4** and **Table 5**.

Table 3 Inundation Times for Commercial Road Levee

Flood	Levee Overtopping Times (hours)			Inundation Times Behind Levee (hours)	
	Time of First Overtopping	Time of Last Overtopping	Duration of Overtopping	Time of Peak Stage	Time to Drain (after Peak)
20% AEP	N/A	N/A	N/A	33	19
5% AEP	N/A	N/A	N/A	36	33
1% AEP	33.5	36.0	2.5	36	64
0.2% AEP	22	32.5	10.5	27	95

Table 4 Inundation Times for East Murwillumbah Levee

Flood	Levee Overtopping Times (hours)			Inundation Times Behind Levee (hours)	
	Time of First Overtopping	Time of Last Overtopping	Duration of Overtopping	Time of Peak Stage	Time to Drain (after Peak)
20% AEP	N/A	N/A	N/A	44	2
5% AEP	N/A	N/A	N/A	45	3
1% AEP	N/A	N/A	N/A	46	8
0.2% AEP	26.4	42.0	15.6	30	24

Table 5 Inundation Times for Dorothy Street Levee

Flood	Levee Overtopping Times (hours)			Inundation Times Behind Levee (hours)	
	Time of First Overtopping	Time of Last Overtopping	Duration of Overtopping	Time of Peak Stage	Time to Drain (after Peak)
20% AEP	N/A	N/A	N/A	51	58
5% AEP	N/A	N/A	N/A	46	64
1% AEP	N/A	N/A	N/A	43	94
0.2% AEP	25.2	47.6	22.4	37	>100

The “time to drain” information presented in **Table 3**, **Table 4** and **Table 5** shows that it would take a minimum of 24 hours to drain the area behind the East Murwillumbah levee following a 0.2% AEP flood. The tables also show that it would take approximately 4 days to fully drain the area behind the Commercial Road levee during a 0.2% AEP event and more than 5 days would be required to drain the area behind the Dorothy Street levee. **Table 5** also shows that it would take at least 2 days to drain the area behind the Dorothy Street levee event even during relatively small floods (e.g., 20% AEP event).

The levee overtopping times in **Table 3** show that overtopping of the Commercial Road would occur about 33 hours after the initial onset of rainfall during the 1% AEP event. During the 0.2% AEP flood, the available warning time would reduce by over 10 hours (i.e., overtopping would commence 22 hours after the initial onset of rainfall). Once the levee overtops, water levels behind the Commercial Road levee would peak after an additional 2.5 to 5 hours. Accordingly, water levels behind the Commercial Road levee are predicted to rise relatively quickly once overtopping of the levee commences.

Table 4 shows that during the 0.2% AEP event, water levels behind the East Murwillumbah levee are predicted to peak about 3 hours after the levee first begins to overtop. Accordingly, floodwaters are also predicted to rise relatively quickly across East Murwillumbah once the levee first begins to overtop.

Conversely, **Table 5** shows that water levels behind the Dorothy Street levee are predicted to peak about 12 hours after the levee first overtops. Accordingly, water levels behind the Dorothy Street levee are comparatively slow to rise.

The outcomes of this assessment have shown that about 1 day of warning would be available during a large flood before overtopping of each levee occurs. Once overtopping commences, water levels are predicted to rise behind the Commercial Road and East Murwillumbah levee relatively quickly (i.e., peaking in as little as 2 hours after the levee overtops). Although water levels are not predicted to rise as quickly behind the Dorothy Street levee, this area would take a considerable amount of time to drain (i.e., ~ 5 days during large floods).

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

5.3 Impacts of Flooding

5.3.1 Impact of Flooding on Key Facilities

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 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 6**.

- **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. In general, access between these evacuation centres and the Murwillumbah District Hospital can be

provided, although shallow inundation depths are anticipated across some connecting roadways during larger floods (water depths of up to 0.3m in some locations).

Table 6 Impact of Flooding on Key Facilities

Facility		1% AEP Flood		0.2% AEP Flood	
		Inundated?	Access Cut?	Inundated?	Access Cut?
Evacuation Centres	*TAFE NSW Murwillumbah and Sacred Heart Catholic Hall* (Murwillumbah St, Murwillumbah)				
SES	*Murwillumbah Unity SES* (Kyogle Rd Murwillumbah)		☑		☑
Fire Stations	*Fire and Rescue NSW Fire Station* (133 Murwillumbah St, Murwillumbah)	-	-	☑	-
Police Stations	*Murwillumbah Police Station* (81 Murwillumbah St, Murwillumbah)			☑	☑
State Emergency Service	*Murwillumbah Unit SES* (LOT 4 Kyogle Rd Murwillumbah)				
Ambulance Stations		There are no ambulance stations located within the study area			
Hospitals	*Murwillumbah District Hospital* (Ewing St, Murwillumbah)				
Schools	*Murwillumbah East Primary School* (Cnr George St and Charles St, Murwillumbah)	☑	☑	☑	☑
	Mount St Patrick College (143 Murwillumbah St, Murwillumbah)				
	Murwillumbah Public School (Prince Street, Murwillumbah)				
	Sathya Sai Primary School (9 Nullum St, Murwillumbah)	☑	☑	☑	☑
	Murwillumbah High School (86 Riverview St, Murwillumbah)				
Preschools / Early Child Care	*UnitingCare Murwillumbah Preschool* (2-6 Byangum Road, Murwillumbah)				
Aged Care Facilities		There are no aged care facilities located within the study area			

- **State Emergency Service (SES):**
  - ***Murwillumbah Unit SES*** (Lot 4 Kyogle Rd Murwillumbah): is located opposite Murwillumbah High School. However, some roads between the SES site and Murwillumbah are subject to inundation. However, these roads are typically cut

early during the flood and would open again before the peak of the flood reaches Murwillumbah.

- **Fire Stations:**
  - ***Fire and Rescue NSW, Murwillumbah*** (133 Murwillumbah St, Murwillumbah): is located on the corner of Murwillumbah St and Queensland Rd. The property experiences flood depths of < 0.3m in all design events up to and including the 1%AEP, and depths of over 1m during the 0.2% AEP event. The property is located on the edge of the floodplain so access to/from the site would be via Queensland Rd, Murwillumbah St and Bent St.
- **Police Stations:**
  - ***Murwillumbah Police Station*** (81 Murwillumbah St, Murwillumbah): is located in the northern portion of the Murwillumbah CBD. The site experiences shallow flows (<0.3m) in all events up to and including the 1% AEP, however depths of over 1 metre are predicted in the 0.2% AEP event. Access is maintained between the police station and evacuation centre during the 1% AEP event, however, access would be cut after 25 hours during the 0.2% AEP event
- **Hospitals:**
  - ***Murwillumbah District Hospital*** (Ewing St, Murwillumbah): is located on elevated ground between the Murwillumbah CBD and East Murwillumbah. The hospital is predicted to remain flood free during each of the simulated design floods and access to/from the hospital and other areas of Murwillumbah should be possible via elevated roadways.
- **Child Care Centres / Preschools:**
  - ***UnitingCare Murwillumbah Preschool*** (2-6 Byangum Road, Murwillumbah): is located at the intersection of Murwillumbah Street and Byangum Road. The centre is located on sufficiently high ground to remain flood free during all design events up to and including the 0.2%AEP.
- **Schools:**
  - ***Murwillumbah East Primary School*** (Cnr George St and Charles St, Murwillumbah): is located outside of the East Murwillumbah levee. Accordingly, inundation of the school is predicted during events as frequent as the 20% AEP event.
  - ***Mount St Patrick College*** (143 Murwillumbah St, Murwillumbah): is bounded by Murwillumbah St, Queensland Rd and Mooball Street. The open space on the school grounds are inundated during relatively frequent flood events (20% AEP). However, the school buildings are not predicted to be inundated during all events up to and including the 0.2% AEP flood. Access along the Murwillumbah Street frontage is maintained throughout all design events.
  - ***Murwillumbah Public School*** (Prince Street, Murwillumbah): is located on the block bounded by Prince St, Eyles Ave, Condong St and Riverview St. Shallow inundation of the southern portion of the school grounds is predicted in all design events (<0.3m deep), and is considered to be a result of sheet flow moving from areas upstream of the school grounds. This is unlikely to pose a significant flood hazard, however, access to/from the school may be cut.
  - ***Sathya Sai Primary School*** (9 Nullum St, Murwillumbah): is located on Nullum Street, opposite Knox Park. Inundation of the school grounds is predicted during

each of the simulated design floods (although a refuge is available on the second floor of the school). Nullum St is predicted to be cut during even small floods (20% AEP flood) and would remain cut for an extended period during particularly large floods (e.g., >90 hours during the 0.2% AEP flood).

- ***Murwillumbah High School*** (86 Riverview St, Murwillumbah): is located on high ground near the SES. Due to its location, the school grounds are not predicted to be inundated by flood waters during any of the design flood events. Although Riverview St is cut in less than 1 hour in the 1% and 0.2% AEP floods, alternate routes exist for evacuation, if needed.

5.3.2 Transportation Impacts

There are a number of major roadways within the Murwillumbah study area 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 35** and **Figure 36**.

In addition to recording road overtopping locations, the time series information from each flood simulations was interrogated to determine:

- The time at which each roadway is first inundated;
- The maximum depth of inundation; and,
- The duration of inundation.

This roadway inundation information is also included on **Figure 35** and **Figure 36**.

The roadway inundation information indicates that:

- **Roadways behind the Commercial Road Levee**
    - Major ponding occurs within Knox Park which results in significant flooding across the adjacent Nullum Street. Access along Nullum Street would be cut after approximately 3 hours during the 1% AEP flood. Access remains cut for 95 hours in the 1% AEP flood and 109 hours in the 0.2% AEP flood.
    - During the 1% AEP flood, a number of roadways surrounding Knox Park also become inundated after around 30 hours. This is predicted to isolate a significant number of properties between Knox Park and Commercial Road during large floods. This means that evacuation via Commercial Road to the evacuation centres may not be possible by the time levee overtopping commences. The roadways are predicted to remain cut for over 30 hours.
- **Roadways behind the East Murwillumbah Levee**
    - The major roadways used for evacuation from East Murwillumbah (Murwillumbah Street and Reynolds Street) are predicted to be cut 27 hours after the initial onset of rainfall during the 1% AEP flood. The roadways are predicted to remain cut for more than 10 hours.

- During the 0.2% AEP flood, Murwillumbah Street is predicted to be cut after only 13 hours. Accordingly, evacuation of East Murwillumbah would need to be completed promptly if a particularly large flood is anticipated.

- **Roadways behind the Dorothy Street Levee**
  - William Street is predicted to be cut in multiple locations. Some locations are predicted to be cut in as little as 2 hours after the onset of rainfall. However, access via alternate roadways would still be possible.

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.

5.3.3 Above Floor Flooding

In an effort to quantify the impact that flooding has across the Murwillumbah CBD, the number of residential and commercial/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 is summarised n **Table 7**. It shows that only a relatively small number of residential properties are predicted to be exposed to above floor flooding during all events up to and including 1% AEP flood. However, a significant number of commercial and industrial properties within the CBD are predicted to be flooded above floor level during relatively frequent floods (e.g., 20% AEP flood). Accordingly, flooding does have the potential to cause financial losses and disrupt business during relatively frequent events.

Table 7 Number of Properties Subject to Above Floor Inundation

Flood Event	Number of buildings with above floor flooding		
	Residential	Commercial/ Industrial	Total Number
20% AEP	1	11	12
5% AEP	1	21	22
1% AEP	2	30	32
0.2% AEP	58	59	117

The number of residential, commercial and industrial properties subject to above floor inundation is predicted to increase significantly during the 0.2% AEP flood when each of the three levees protecting the town are overtopped.

5.3.4 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 the

Murwillumbah CBD study area. A detailed description of the approach used to establish the flood damage cost estimates is provided in **Appendix G**.

As outlined in **Appendix G**, 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 / Industrial properties
- Infrastructure

The final flood damage estimates for each design flood are summarised in **Table 8** for existing topographic and development conditions. It indicates that if a 1% AEP flood was to occur, $4.65 million worth of damage could be expected across the Murwillumbah CBD (note that this damage estimate does not include any areas outside of the levee system, including South Murwillumbah). The majority of the damage is predicted to occur across commercial or industrial properties.

Table 8 also shows a significant increase in flood damage costs between the 1% AEP and 0.2% AEP floods. Accordingly, once significant overtopping of the levee occurs, flood damage costs can be expected to increase exponentially.

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.

Table 8 Summary of Flood Damage Costs for Existing Conditions

Flood Event	**Flood Damages** ($ millions)		
	Residential	**Commercial/ Industrial**	**Total Damages**
20% AEP	1.96	0.23	2.19
5% AEP	2.38	0.38	2.76
1% AEP	3.50	1.15	4.65
0.2% AEP	22.3	43.3	65.7
PMF	54.9	56.1	111

The individual AAD estimates for each property were summed to provide an estimate of the total damage likely to be incurred across the study area on an annual basis for existing topographic and development conditions. The AAD for Murwillumbah was determined to be **$1.11 million**. Accordingly, if the “status quo” was maintained, residents and business owners within the catchment as well as infrastructure providers, such as Council, would likely be subject to cumulative flood damage costs of approximately $1.11 million per annum (on average).

5.4 Sensitivity Assessment

5.4.1 Overview

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

However, the flood modelling does include some parameters that are not known with certainty. Furthermore, failure of the pumps or levees 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 additional sensitivity simulations were completed. This included:

- Climate change assessment
- Failure of each levee
- Failure of each pump
- 2016 version of Australian Rainfall & Runoff

The outcomes of each sensitivity assessment are presented below.

5.4.2 Climate Change

Although there is considerable uncertainty associated with the impact that climate change may have on rainfall, it was considered important to provide an assessment of the potential impact that rainfall intensity increases may have on the flood risk across the study area. Therefore, additional 1% AEP simulations were completed to reflect the following potential future rainfall intensity increases:

- 10% increases in rainfall
- 20% increases in rainfall
- 30% increase in rainfall

The peak flood level results from the climate change simulations were extracted and were subtracted from 'existing' 1% AEP 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. The difference mapping is presented in **Plates 10** to **12**.

The total number of buildings exposed to above floor inundation as well as the total flood damages were also extracted for each climate change simulation and are presented in **Table 9**.

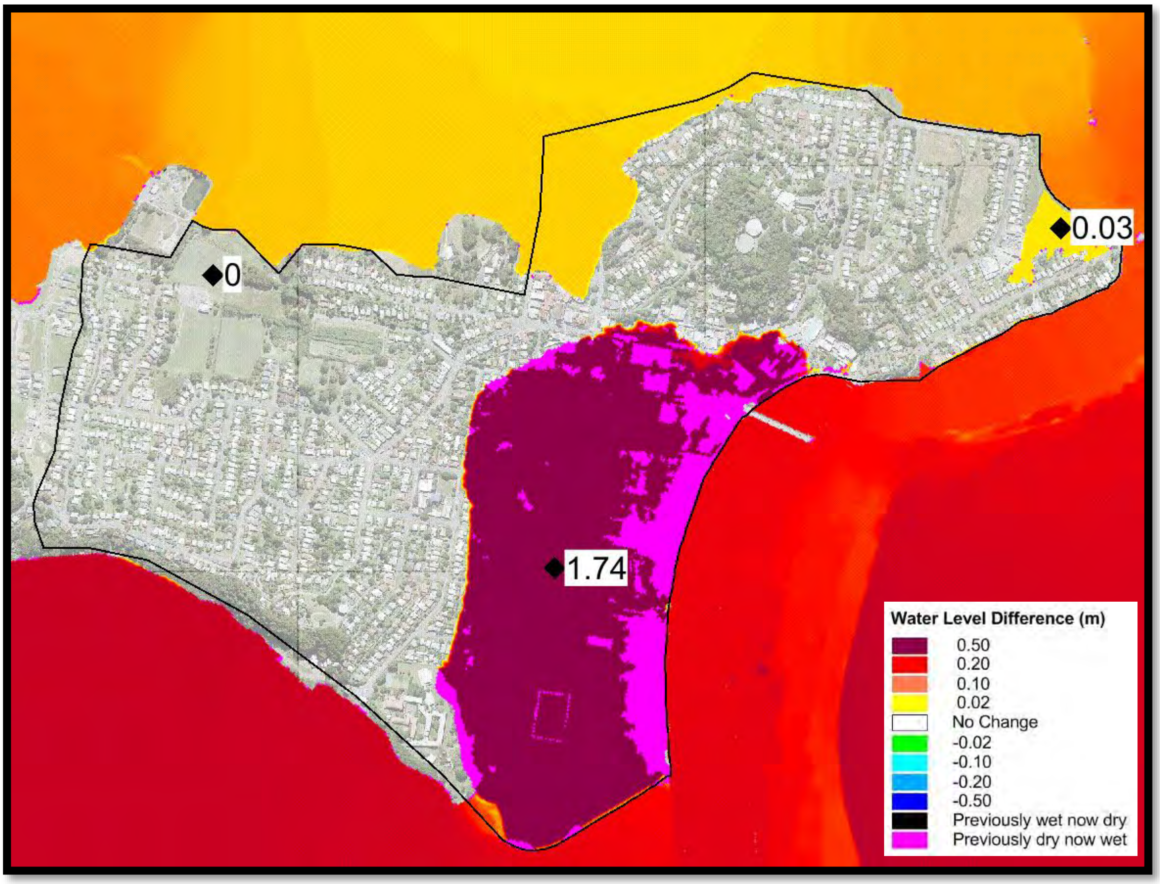


Plate 10 Peak 1% AEP Flood Level Difference Mapping for 10% Increase in Rainfall Scenario

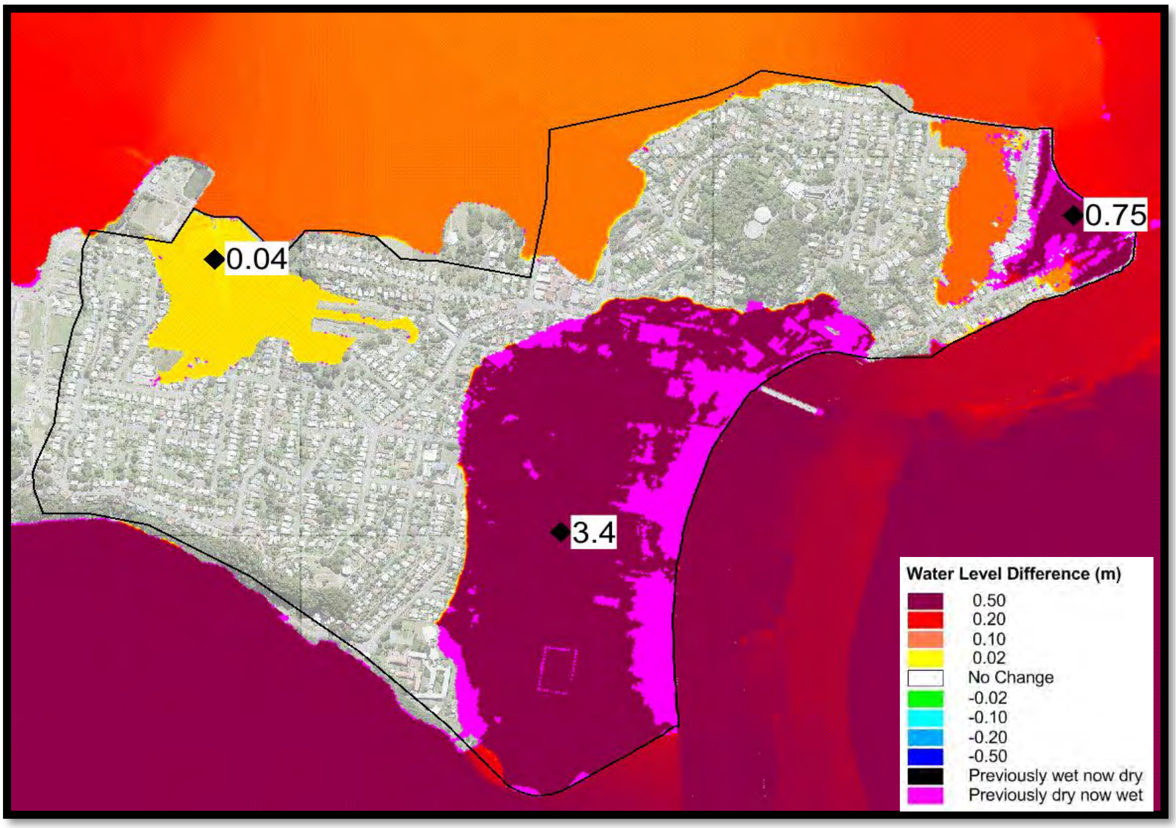


Plate 11 Peak 1% AEP Flood Level Difference Mapping for 20% Increase in Rainfall Scenario

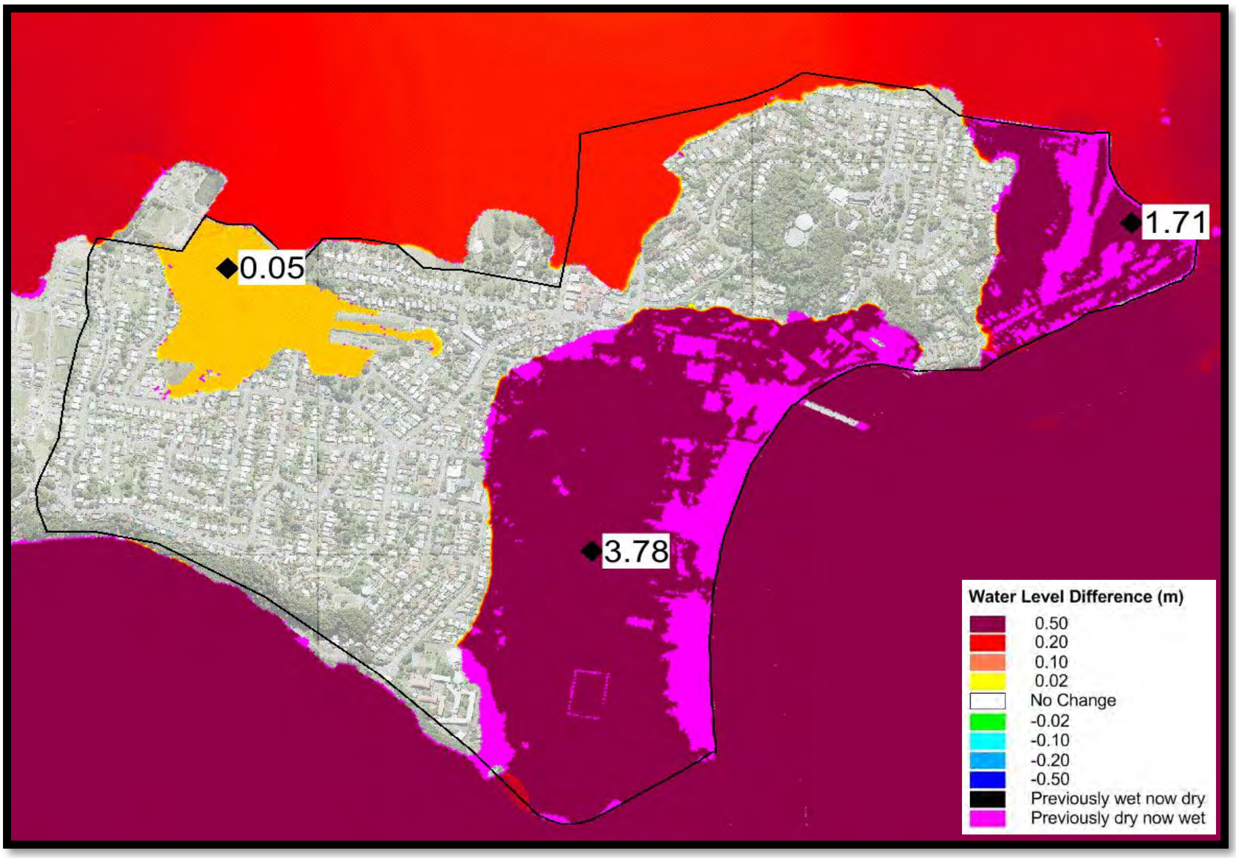


Plate 12 Peak 1% AEP Flood Level Difference Mapping for 30% Increase in Rainfall Scenario

Table 9 Predicted Climate Change Impacts

Metric	Existing	Climate Change		
		10% Increase in Rainfall Intensity	20% Increase in Rainfall Intensity	30% Increase in Rainfall Intensity
Buildings Flooded Above Floor Level	32	**55** (72% increase)	**68** (113% increase)	**92** (188% increase)
Flood Damage ($ millions)	4.65	**29.8** (540% increase)	**58.2** (1152% increase)	**64.4** (1285% increase)

As shown in **Plates 10** to **12**, rainfall intensity increases have the potential to cause significant increases to existing 1% AEP inundation depths and extents. Furthermore, **Table 9** shows that rainfall intensity increases would also increase the number of properties exposed to above floor inundation and would significantly increase flood damage costs. The most notable impacts are predicted to occur behind the Commercial Road levee. More specifically, during the 1% AEP with 10% increase in rainfall intensity, the increased volume of runoff is predicted to increase flood levels/depths behind the levee by over 1.7 metres. Areas protected by the East Murwillumbah and Dorothy Street levees are not predicted to experience a significant change in existing flood levels with a 10% increase in rainfall.

Flood level impacts across East Murwillumbah are more significant during the 20% increase in rainfall scenario, where flood level increases of about 0.75 metres are predicted. This is associated with a large section of the levee system being overtopped during this scenario. Flood level increases behind the Commercial Road levee are also significant during this scenario, with increases of 3.74 metres predicted. Flood level increases behind the Dorothy Street levee are minor during this scenario.

The 30% increase in rainfall intensity scenario is predicted to further increase the flood level impacts behind the Commercial Road and East Murwillumbah levees. However, even under the 30% increase in rainfall scenario, the Dorothy Street levee is not predicted to be overtopped. Therefore, flood level increases are predicted to be small.

The results of the climate change sensitivity assessment show that Murwillumbah is sensitive to rainfall intensity increases. Therefore, if rainfall intensities do increase in the future, it does have the potential to significant increase the existing flood risk and financial impacts beyond that documented in the previous sections, particularly across those areas located behind the Commercial Road levee.

5.4.3 Levee Failure

Each of the three levees that form part of this study were assumed to remain intact as part of each design flood simulation. However, there is the potential that the levee system could fail during a future flood. This failure may result in a significant increase in flood risk for those properties located behind each levee system.

Therefore, an additional 1% AEP simulation was completed incorporating a failure of each levee. The levees were assumed to fail based upon the method described by Von Thun and Gillette in '*Guidance on Breach Parameters'* (1990). The breach parameters that were adopted for are provided in **Table 10** and **Plate 13**.

It was assumed that each levee would beach at the point where it is first overtopped. It was also assumed that the breach propagated to form a trapezoidal shape, as shown in **Plate 14**, and that the failure initiated at the peak of the 1% AEP flood.

Table 10 Adopted Levee Break Parameters

		Commercial Road Levee	**East Murwillumbah Levee**	**Dorothy Street Levee**
Levee Type at Failure Location		Earthen	Earthen	Earthen
Levee Wall Crest Elevation (mAHD)		7	5.79	4.9
Bottom of Wall Elevation (mAHD)		2.5	4.3	2
Time of Levee Failure (hours since start of storm)		34.5	35.5	35.5
Duration of Failure (hours)		0.34	0.28	0.31
Water level at failure time (mAHD)				
W_b	Refer to Plate 10 for description of each parameter	12.9	8.3	10.5
B_t		21.9	11.3	16.3
H_b		4.5	1.5	2.9
Side Slope		1H:1V		

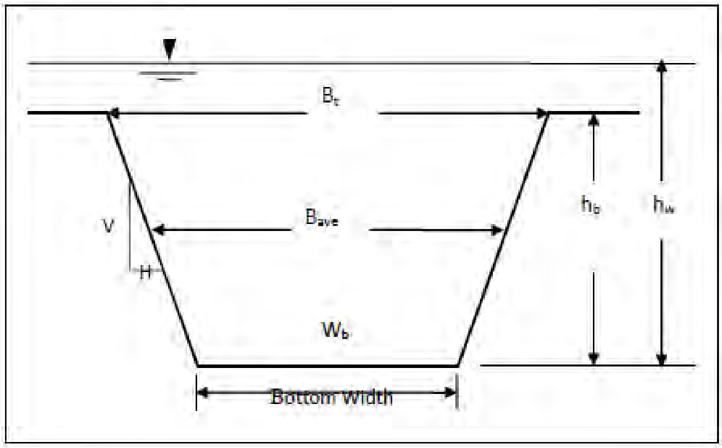


Plate 13 Adopted levee break parameters

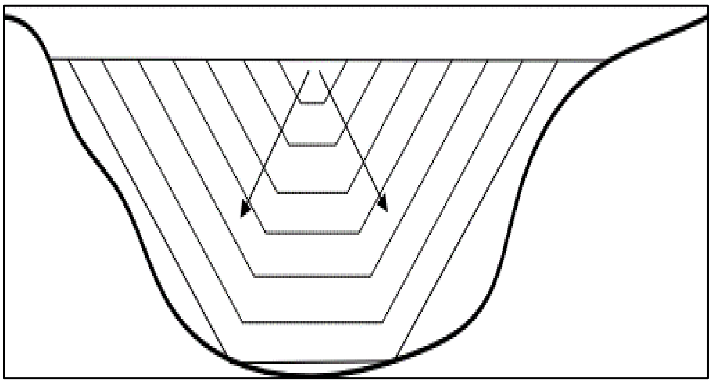


Plate 14 Adopted levee break propagation

The levee break 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 1% AEP with the levee break.

Flood level difference mapping was prepared for the 1% AEP levee break scenario and is presented in **Plate 15**. Velocity difference mapping was also prepared to quantify the impact that the sudden failure of the levee system would have on peak velocities in the vicinity of the breach. The velocity difference mapping is provided in **Plate 16**.

The flood level difference mapping shown in **Plate 15** shows that a breach of the Commercial Road levee will increase flood levels by 2.8 metres and will result in a significant increase in inundation area (refer magenta areas in **Plate 15**). A breach of the East Murwillumbah levee is predicted to increased flood level by up to 1.1 metres. The impact behind the Dorothy Street Levee is less significant, with flood level increases of about 0.4 metres.

The velocity difference mapping shown in **Plate 16** shows some significant increases in velocity in the immediate vicinity of each breach location (velocity increases of up to 6 m/s are anticipated). The most significant increases occur near the Commercial Road Levee breach location. Fortunately, the most significant velocity increases extend across open space/playing fields. Nevertheless, if the breach was to occur closer to existing development it does have the potential to significantly increase the flood hazard (i.e., potential risk to life and potential for structural failure of buildings).

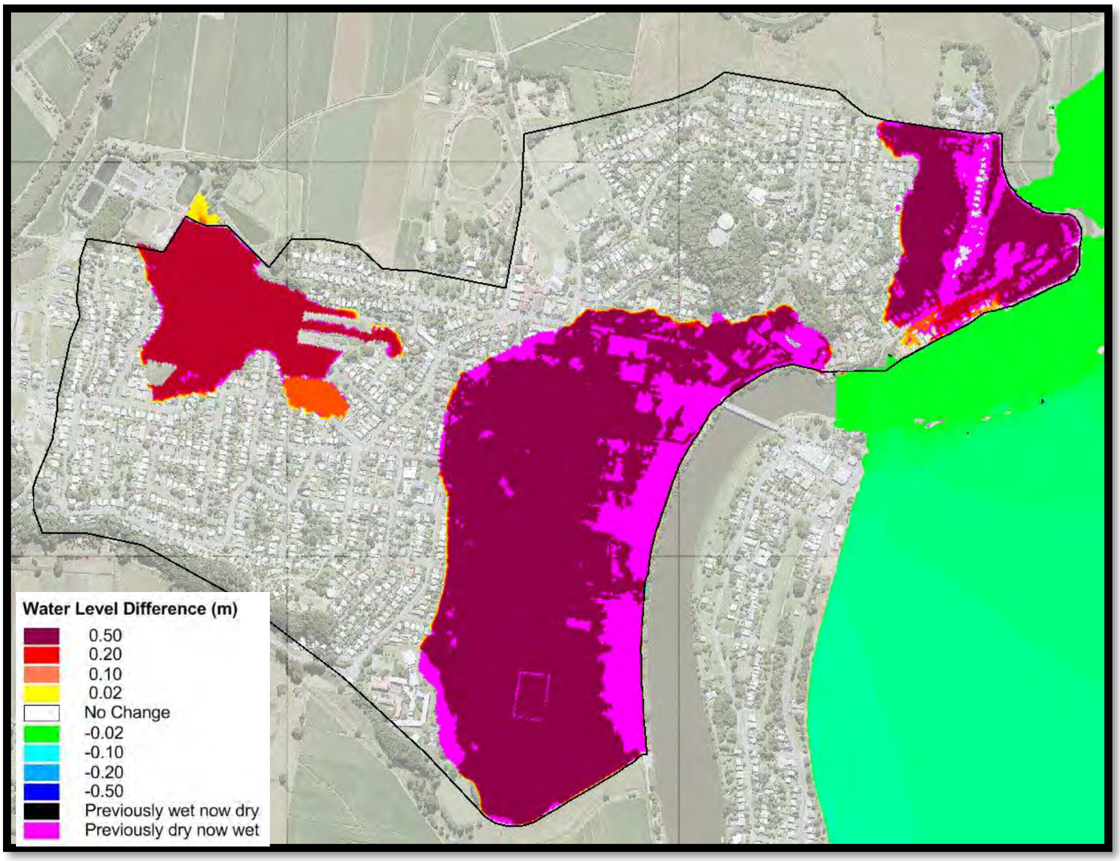


Plate 15 Peak 1% AEP Flood Level Difference Mapping for the Levee Breach Scenario

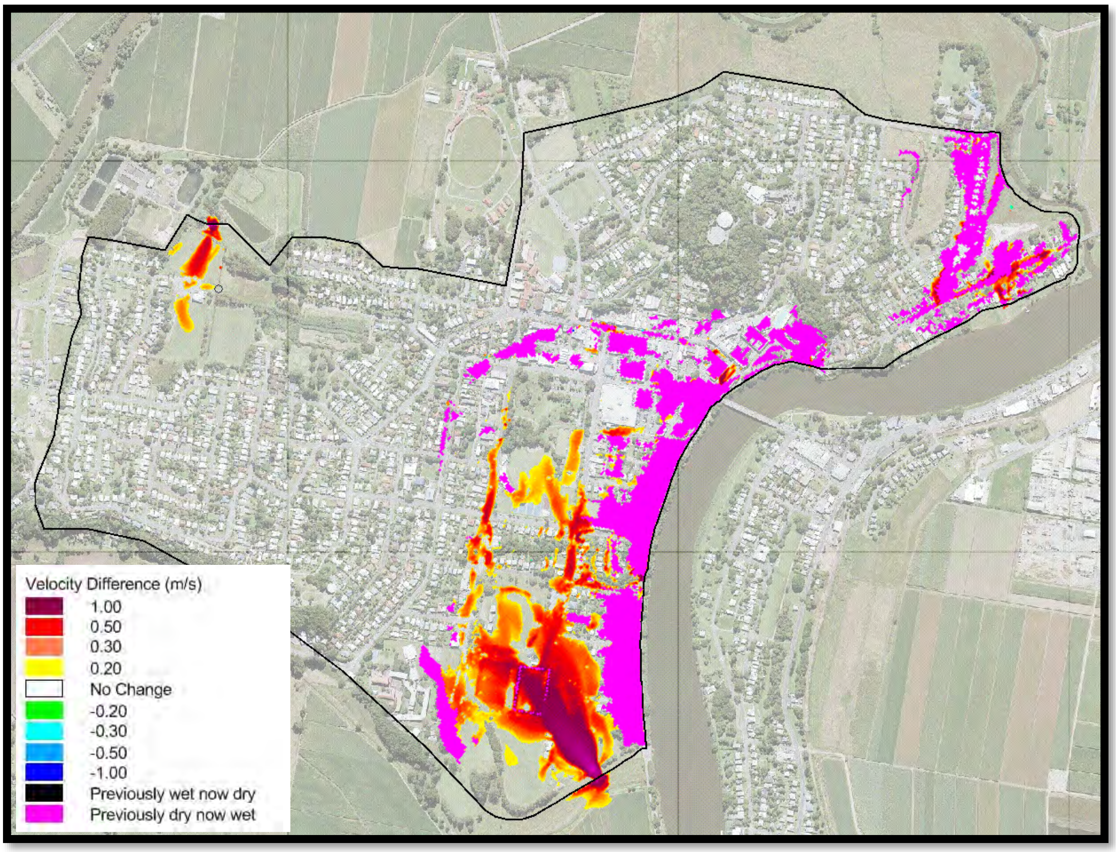


Plate 16 1% AEP Velocity Difference Mapping for the Levee Breach Scenario

Stage hydrographs (describing the time variation in water level) were extracted at various locations behind the levee system for the 1% AEP flood for existing conditions as well as under levee failure conditions. The stage hydrographs are presented in **Appendix K** and confirm a significant increase in peak flood level that occurs over a very short timeframe. Accordingly, the stage hydrographs indicate that there would be minimal time for emergency services and the broader community to react and act should a breach of the levee occur.

Overall, the outcomes of the levee breach sensitivity analysis highlight the importance of ensuring the condition of the levee system is continually monitored and maintained to ensure the potential for failure minimised.

5.4.4 Pump Failure

As discussed in Section 2.6, two pump systems assist in draining the area contained behind the Commercial Road levee. It is understood that the existing pumps system have occasionally failed (e.g., the Lavender Creek pump station failed during the January 2013 flood). Therefore, an additional sensitivity assessment was completed to quantify the impact that complete failure of the pump systems would have on design flood behaviour behind the Commercial Road levee.

Additional simulations were completed for the 20%, 5%, 1% AEP and 0.2% AEP floods assuming that the pumps did not operate for the full duration of each event. Flood level difference mapping was prepared for the 20%, 5% and 1% AEP floods and is presented in **Plates 17** to **19**.

Stage hydrographs for the 1% AEP event were also extracted at various locations behind the levee with the pump failure and are presented in **Appendix K**.

Plate 17 indicates that during the 20% AEP, flood level increases of between 0.1 and 0.2 metres are anticipated (the largest flood level increases are predicted to the south of Lavender Creek). Flood level impacts are predicted to increase during the 5% AEP flood as well as the 1% AEP flood (increases of over 0.2 metres are predicted). This indicates that even in instances where the levee overtops (such as the 1% AEP flood), the pumps remove a sufficient volume of runoff in the leadup to the levee overtopping to provide a net reduction in flood levels.

If the pumps fail, 2 additional commercial properties are predicted to be inundated above floor in a 20% AEP flood and 3 additional commercial properties are predicted to be inundated above floor level in a 5% AEP flood. There would negligible change in the number of buildings subject to above floor flooding during the 0.2% AEP flood indicating that the pumps play an important role during more frequent events but would be overwhelmed when significant levee overtopping occurs.

Average annual damages were also recalculated with the pump failure and determined that, if the pumps do not operate, AAD could be expected to increase by approximately $100,000. Therefore, if the pumps were to fail regularly, flood damages could be expected to increase by approximately 10% (on average).

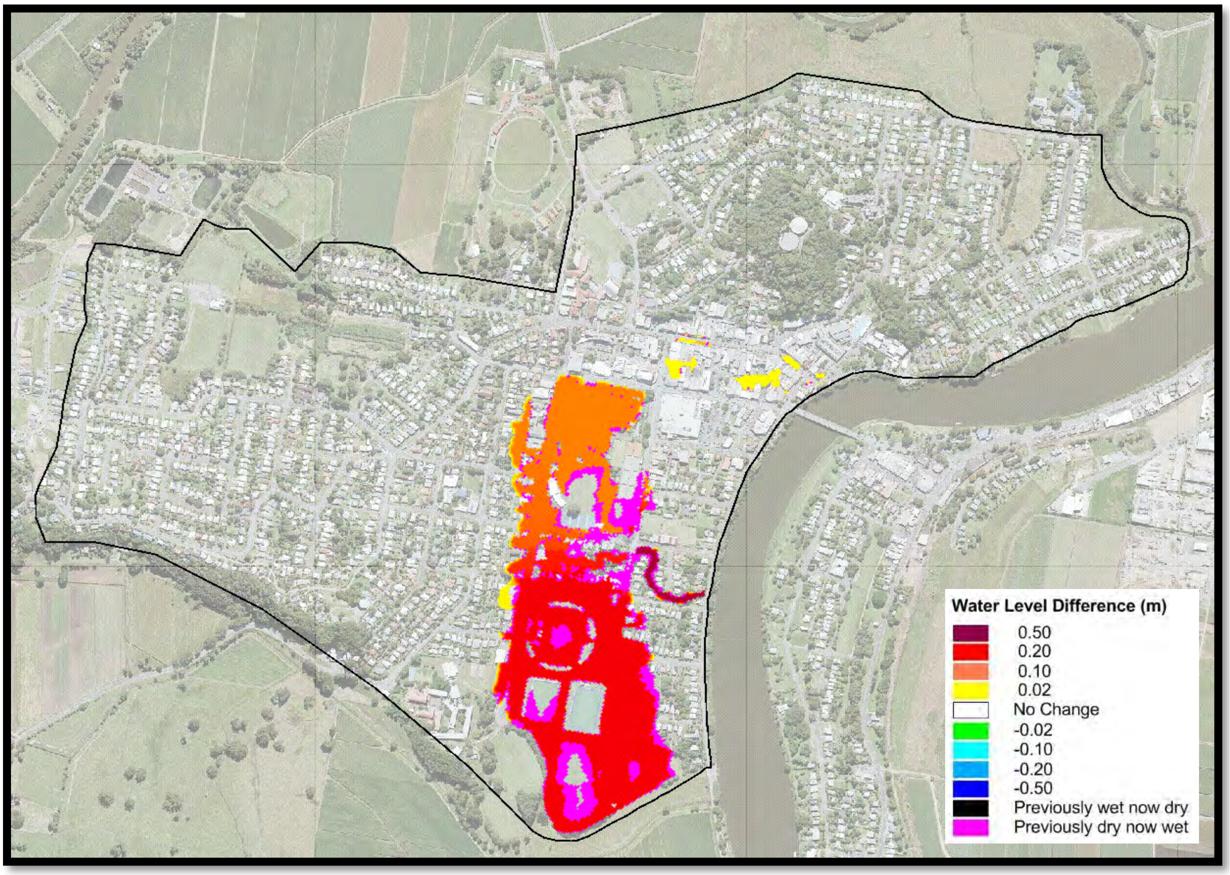


Plate 17 Peak 20% AEP Flood Level Difference Mapping for Pump Failure Scenario

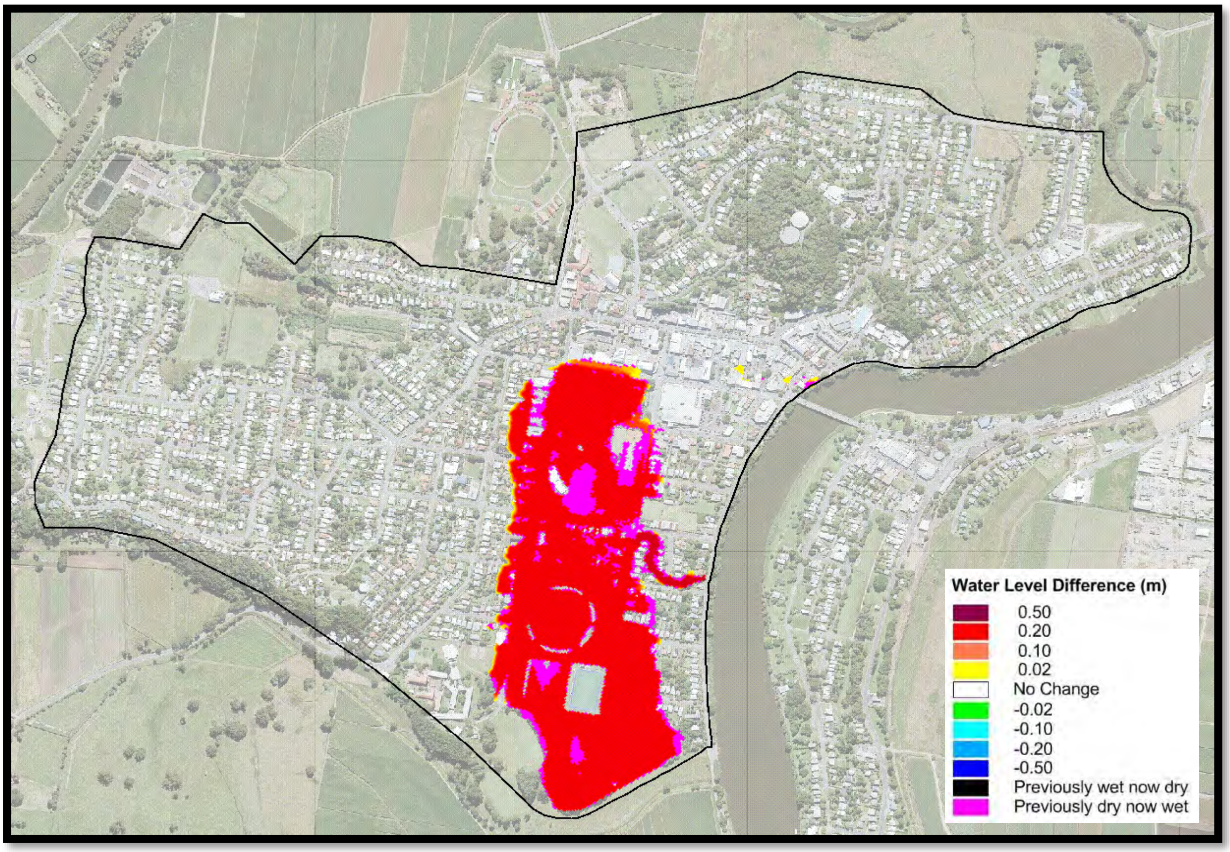


Plate 18 Peak 5% AEP Flood Level Difference Mapping for Pump Failure Scenario

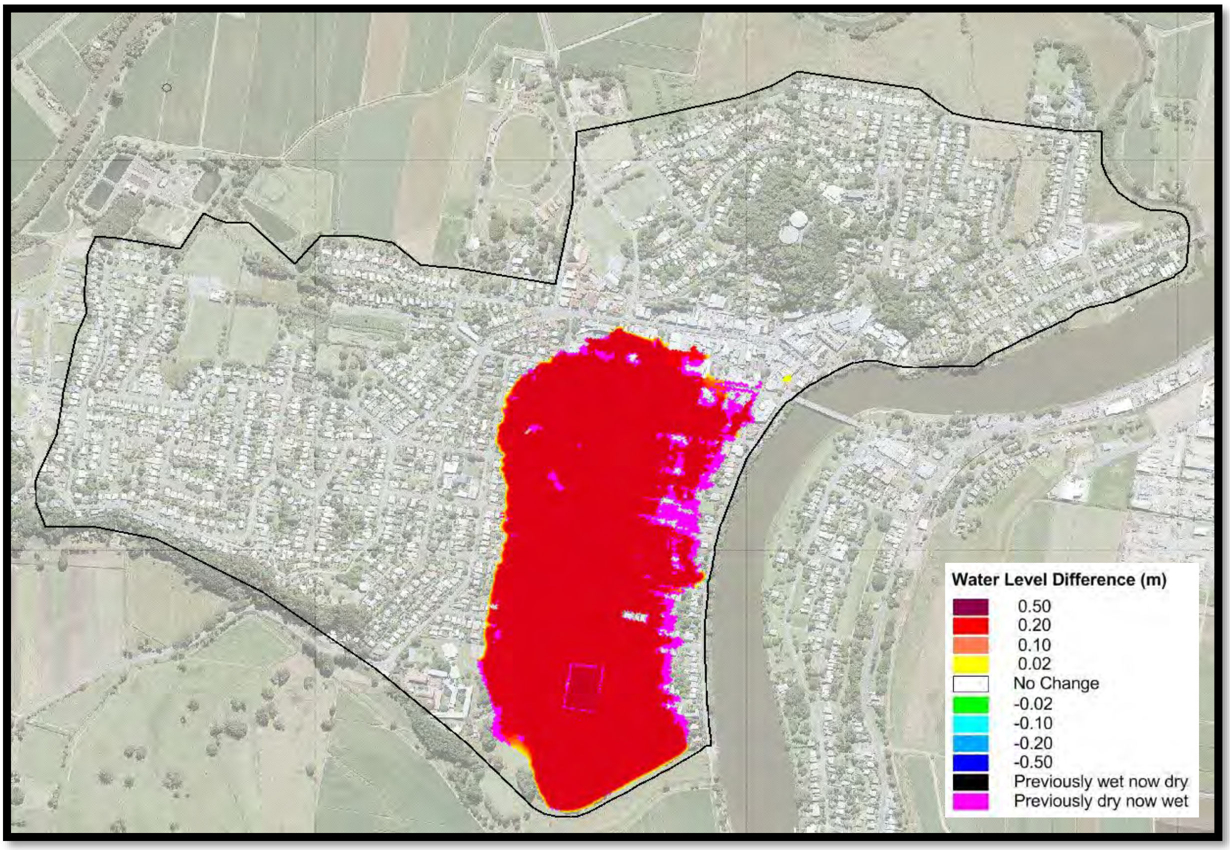


Plate 19 Peak 1% AEP Flood Level Difference Mapping for Pump Failure Scenario

The stage hydrographs in **Appendix K** emphasise that failure of the pumps will result in a more rapid rise in flood level behind the levee, a higher peak flood level as well as a much longer time to drain the area behind the levee. Accordingly, there failure of the pump system will negatively impact on flood behaviour behind the Commercial Road levee in multiple ways.

Overall, the outcomes of the pump failure sensitivity analysis show that the existing pump systems do play an important role in reducing design flood levels behind the Commercial Road levee during both frequent and more severe floods. However, during particularly large floods (e.g., 0.2% AEP), the pumps do not have sufficient capacity to make a significant difference.

5.4.5 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 and the commencement of the *'Murwillumbah CBD Levee & Drainage Study'*, a revised version of Australian Rainfall and Runoff has been 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 Murwillumbah. The outcomes of this assessment is contained within **Appendix F**.

The outcomes of this sensitivity assessment have determined that ARR2016 will produce some notable changes in 1% AEP flood levels when compared with ARR1987. Across most of the study area (e.g., East Murwillumbah and adjoining the Dorothy Street levee), ARR2016 generates lower peak flood level estimates relative to ARR1987. In these areas, it appears the volume of runoff has a greater impact on flood levels despite ARR2016 producing higher discharges. Accordingly, the use of the longer duration ARR1987 hydrographs is predicted to provide more conservative flood level estimates across these areas.

However, in the vicinity of the Commercial Road levee, ARR2016 produces peak 1% AEP flood levels that are up to 0.3 metres higher than ARR1987. This is predicted to significantly increase 1% AEP flood levels in areas behind the Commercial Road levee. It is also noted that the consideration of a 12-hour ARR2016 storm duration instead of a 36-hour ARR1987 storm duration is likely to significantly reduce the available flood warning time. Accordingly, the use of ARR1987 hydrology may be underestimating the flood risk across the Murwillumbah CBD. In order to maintain continuity with the *'Tweed Valley Flood Study'* (BMT WMB, 2009), the ARR1987 hydrology was retained for the current study. However, further consideration of the ARR2016 hydrology should be completed as part of future investigations, particularly if options such as levee raising are pursued.

6 OPTIONS FOR MANAGING THE FLOODING RISK

6.1 Overview

The results documented in Chapter 4 indicates that flooding behind each of the three levees that protect Murwillumbah, either from local catchment runoff or levee overtopping can impose a significant financial burden on residents and business owners and, in rare floods, pose a risk to life.

The following sections describe measures that could be potentially implemented to help mitigate the existing flood risk. In general, flood risk reduction measures can be broadly grouped into 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.
- **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.
- **Response Modification Options**: are measures that can be implemented to change the way in which emergency services as well as the general public responds before, during and after a flood. Response modification measures are the key measures employed to manage the continuing flood risk.

6.2 Options for Managing the Existing Flooding Problems

A meeting was held with Tweed Shire Council and a presentation was made to the Tweed Shire Council Floodplain Risk Management Committee part way through the study to discuss potential options for addressing the flooding risk. A summary of the options that were discussed at the meeting are included in **Table 11**.

The meeting attendees discussed the relative advantages and disadvantages of each option to determine the potential feasibility of each option. Additional options were also identified during the meeting. Based upon professional experience and feedback received from Council and the Committee, the options summarised in **Table 11**Error! Reference source not found. were considered appropriate for more detailed hydraulic analysis.

Table 11 Options Considered for Managing the Flooding and Drainage Problems

Description of Option
Modification of the operation of the existing Lavender Creek pumps to allow the pump flow rates to be varied based on the upstream water level
Augmenting existing pump system to include backup power supply
Provide additional capacity to Wharf Road pump
Installation of additional pump in Proudfoots Lane to convey runoff (from Knox Park and Proudfoot's Lane) to the northern side of Mount St Patrick College
Installation of new pump systems to drain the area behind the Dorothy Street Levee and East Murwillumbah Levee
Increasing the height of the southern section of the Commercial Road levee
Inclusion of dedicated "spillway" on Commercial Road levee
Installation of cameras so flooding can be monitored in real time
Increasing the height of the East Murwillumbah levee near the Primary School
Excavation of the Knox Park duck pond to provide additional flood storage capacity
Dredging of the river to provide additional flow carrying capacity
Re-design of Commercial Road levee gates to allow them to "open" and release water back into the Tweed River during levee overtopping events
Provision of high level "relief" culverts in levee to allow water to drain from behind the levee back into the Tweed and Rous Rivers
Installation of "agriculture pipe" enclosed in trenches filled with aggregate to assist in draining low lying areas
Stormwater drainage upgrades for Proundfoot Lane
Stormwater drainage upgrades for Nullum Lane
Stormwater drainage upgrades for William Street (near Dorothy Street)
Regrading of William Street (near Dorothy Street)
Regrading near intersection of Commercial Road / Wharf Street
Planning modifications to reduce potential for increased population density on eastern side of Knox Park
Real time flood gauging and warning system
Updates to the Local Flood Plan
Community education schemes (particularly for Commercial Road properties)
Property specific measures for flood protection (i.e. Temporary Flood Barriers)

Table 12 Options Selected for Detailed Investigations

Option		
Flood Modification Measures	A	Increasing height of East Murwillumbah levee and Commercial Road levee including provision of dedicated spillway
	B	Include new "low flow" pump and change operational procedures for Lavender Creek pump plus upgrade Wharf Street pump. Install new pump systems behind Dorothy Street and East Murwillumbah Levees
	C	New Proudfoots Lane pump system
	D	Regrading of William Street near the intersection of Commercial Road / Wharf Street
	E	Drainage upgrades in Proudfoots Lane, Nullum Lane and William Street
	F	Re-design of Commercial Road levee gates
Planning Modification Measures	G	Planning recommendations
	H	Property specific measures for flood protection (i.e. Temporary Flood Barriers)
Response Modification Measures	I	Local Flood Plan updates
	J	Real time flood gauging and warning system
	K	Community education

6.3 Assessment of Options

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 was evaluated against a range of criteria to provide an initial appraisal of the potential feasibility of each option, including:

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

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 always improve emergency response.

6.3.1 Hydraulic Impacts

Flood 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.

To assess the hydraulic impact of each flood modification option, 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.

A focus was placed on showing flood level differences during the 20% AEP as well as the 1% AEP floods to show how the option performed during a relatively small event as well as a larger flood. In instances where an option had the potential to change the duration of inundation, time of inundation difference mapping was also prepared.

6.3.2 Change in Number of Buildings Inundated Above Floor Level

An assessment of the change in the number of buildings subject to above floor inundation during each design flood was also completed for each option. A focus was placed on the change in the number of buildings inundated during the 1% AEP flood. However, smaller and larger floods were also considered in the assessment.

6.3.3 Financial Feasibility

A preliminary economic assessment of each option 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. A BCR of greater than 1.0 shows that the present value of benefits outweighs the present value of costs of the option and provides an indicator that the option may provide a net economic benefit over the life of the option.

From a flooding perspective, economic 'benefits' were quantified as the reduction in flood damage costs if the option is implemented. The benefits of each option were estimated 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, 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.

6.3.4 Community Acceptance

Floodplain risk management options do have the potential to impact on the broader community in both beneficial and adverse ways. For example, elevating a levee may reduce the frequency of levee overtopping/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.

As outlined in Section 2.8, a community questionnaire was distributed to property owners within the study area. The questionnaire provided the community with a preliminary 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.

6.3.5 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.

6.4 Flood Modification Options

6.4.1 Option A - Levee Raising

Description of Option

This option would involve elevating the existing Commercial Road and East Murwillumbah levees to reduce the overtopping frequency. The extent of the works associated with this option are shown in **Figure H1** in **Appendix H** and would include:

- Elevating the southern part of the Commercial Road levee (earthen embankment) to provide protection during all events up to and including the 1% AEP (including a 0.5m freeboard).
- Construction of a spillway near the sporting fields located immediately south-east of Murwillumbah High School. The spillway would help to ensure that overtopping of the Commercial Road levee first occurs in a controlled manner in an area located away from existing development (the spillway would be located 0.2 metres above the peak level of the 1% AEP flood).
- Elevating the East Murwillumbah levee to ensure that a minimum of 0.3 metres of freeboard will be provided above the peak 1% AEP flood level. This will primarily involve works in the immediate vicinity of the East Murwillumbah Primary School.

Hydraulic Benefits

The TUFLOW model was updated to include the elevated levee system and was used to re-simulate the 1% AEP and 0.2% AEP floods. As the Commercial Road and East Murwillumbah levees do not currently overtop during the 20% AEP and 5% AEP floods, these events were not re-simulated with the upgraded levee system.

Flood level difference maps were prepared for the 1% AEP and 0.2% AEP floods and are presented in **Plates 20** and **21** respectively. The change in number of buildings exposed to above floor inundation was also calculated based on the results of the design flood simulations. This information is summarised in **Table 13**.

Table 13 Change in Number of Buildings Inundated Above Floor Level for Levee Upgrade

Design Flood	Change in number of buildings with above floor inundation		
	Residential	**Commercial/Industrial**	**Total Number**
20% AEP	0	0	0
5% AEP	0	0	0
1% AEP	0	-4	-4
0.2% AEP	0	0	0
PMF	0	0	0

Plate 20 shows that the levee modifications would prevent overtopping of the Commercial Road levee during the 1% AEP event. This would provide flood level reductions of nearly 0.5 metres behind the levee. This is predicted to result in 4 fewer commercial properties being inundated above floor level during the 1% AEP flood.

Plate 20 also shows that the levee raising is not predicted to produce any significant flood level increases during the 1% AEP event in areas outside of the levee (e.g., south of the CBD). This is associated with the raised levee only displacing a relatively small amount of water at the peak of the 1% AEP flood. More specifically, under existing conditions, the southern part of the Commercial Road levee is overtopped for about 2 hours and the peak 1% AEP flow over the levee is predicted to be 3.5 m^3/s. Accordingly, the volume of flow over the levee during the 1% AEP event is minimal when compared to the total 1% AEP flow volume along the Tweed River (i.e., peak flow >5,000 m^3/s and flow duration >40 hours).

Plate 21 shows that the levee modifications would also provide flood level reductions behind the Commercial Road levee during the 0.2% AEP event. Some reductions in 0.2% AEP flood levels are also predicted in the Tweed River which extend into parts of South Murwillumbah (maximum 0.04m reduction). However, the elevated levee is predicted to produce increases of up to 0.15 metres immediately south of the levee. These flood level increases are predicted to extend upstream along the Tweed River to the Bray Park weir (approximately 2 km south-west of the levee) as well as across the Dunbible Creek floodplain (approximately 3 km south of the levee). Although the majority of the flood level increases are predicted to extend across areas of open space (e.g., pastures and sugar cane), existing residential properties adjoining Kyogle Road, Thomas Street, Countryside Drive and Tombonda Road at Bray Park are also predicted to be impacted.

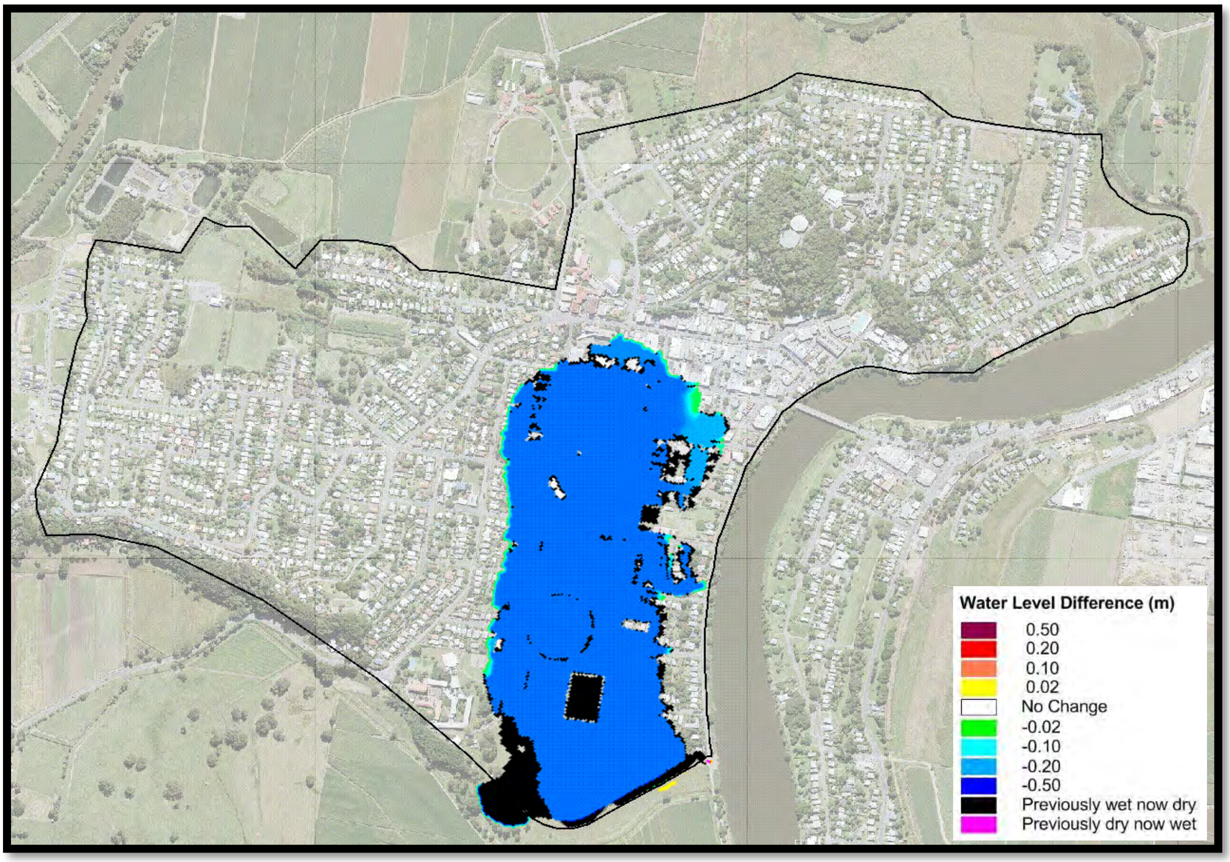


Plate 20 Peak 1% AEP Flood Level Difference Mapping for Levee Upgrade

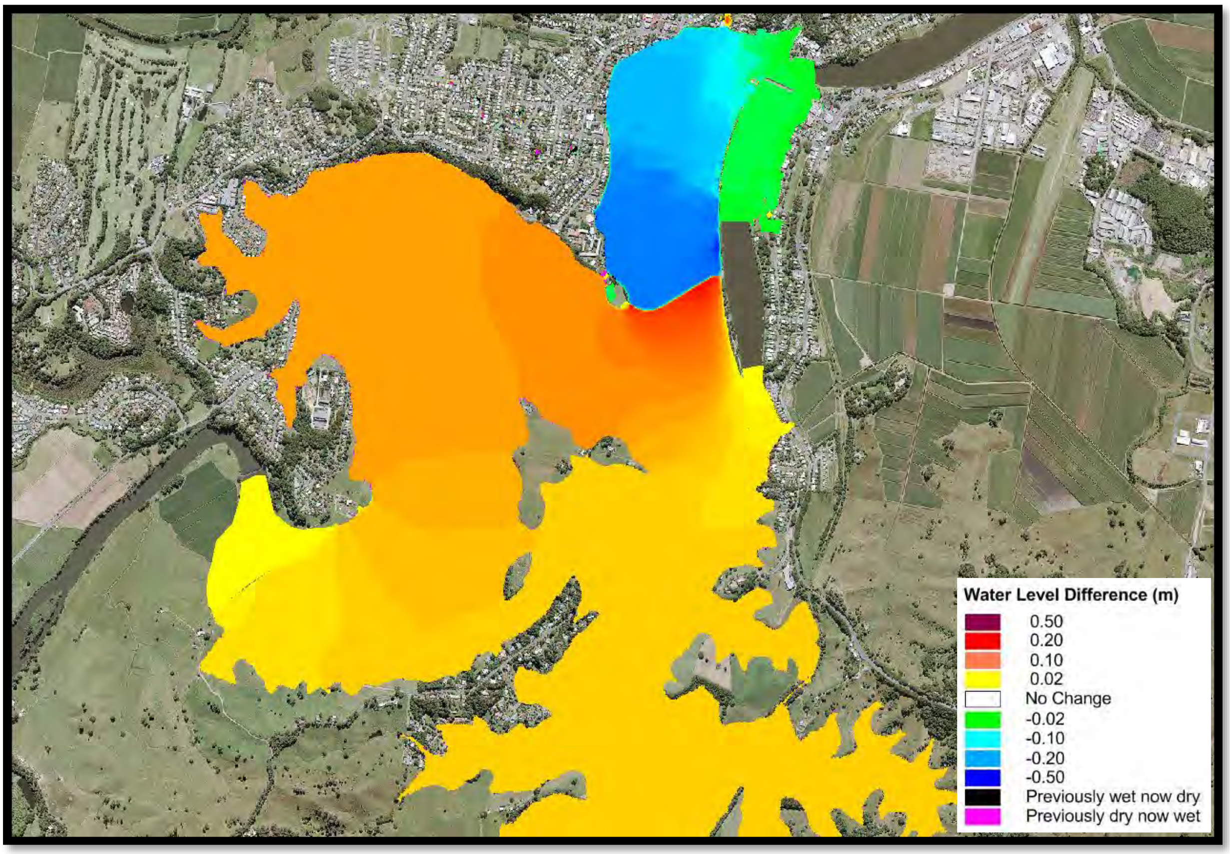


Plate 21 Peak 0.2% AEP Flood Level Difference Mapping for Levee Upgrade

The more significant adverse flood impacts during the 0.2% AEP event is associated with the raised levee displacing a more significant volume of water during this event. Unlike the 1% AEP event, where the peak flow over the levee was only 3.5 m^3/s, during the 0.2% AEP event, the peak flow across the southern section of the existing Commercial Road levee is predicted to exceed 400 m^3/s and the levee will be overtopped for around 10 hours. Accordingly, raising of the levee will displace a much greater volume of water during the 0.2% AEP flood.

Plates 20 and **21** shows that negligible flood level reductions are predicted behind the East Murwillumbah levee during the 1% AEP and 0.2% AEP events.

Economic Benefits

It is expected that the levee modifications would cost approximately $4.6 million to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

A revised damages assessment was completed based on the results of the revised simulations. This determined that average annual flood damages could be expected to reduce by $18,000 per annum. This would provide a total reduction in flood damage costs of $253,000 over the 50-year design life of the levee. This provides a preliminary benefit-cost ratio(BCR) of 0.06, which indicates that the costs associated with implementation of the levee upgrades far outweigh the reduction in flood damage costs.

The poor performance of the upgraded levee system from a financial standpoint is primarily associated with the levee not affording benefits during the more frequent events (i.e., significant benefits are only afforded during the 1% AEP flood).

Community Acceptance

The levee upgrade was generally supported by the community with the majority of the community "strongly supporting" the option (refer **Plate 22**). There were some community members that were against the options citing that elevating the levee may provide a false sense of security for those living behind the levee and dissuade the community from early evacuation.

Emergency Response Benefits

A review of inundation times indicates that during the 0.2% AEP flood, 4 additional hours of time would be provided to those properties located behind the Commercial Road levee. As discussed, overtopping of the levee would also be prevented during the 1% AEP flood. Therefore, the levee upgrade would afford some emergency response benefits (in terms of reduced frequency of levee overtopping and additional evacuation time).

However, as noted above, elevating the levee may also reduce incentives for early evacuation by the community. This may increase the reliance on the SES during events that overtop the levee. Therefore, if this option was pursued it would need to be supplemented with an appropriate community education property highlighting the potential risks of living behind the levee system.

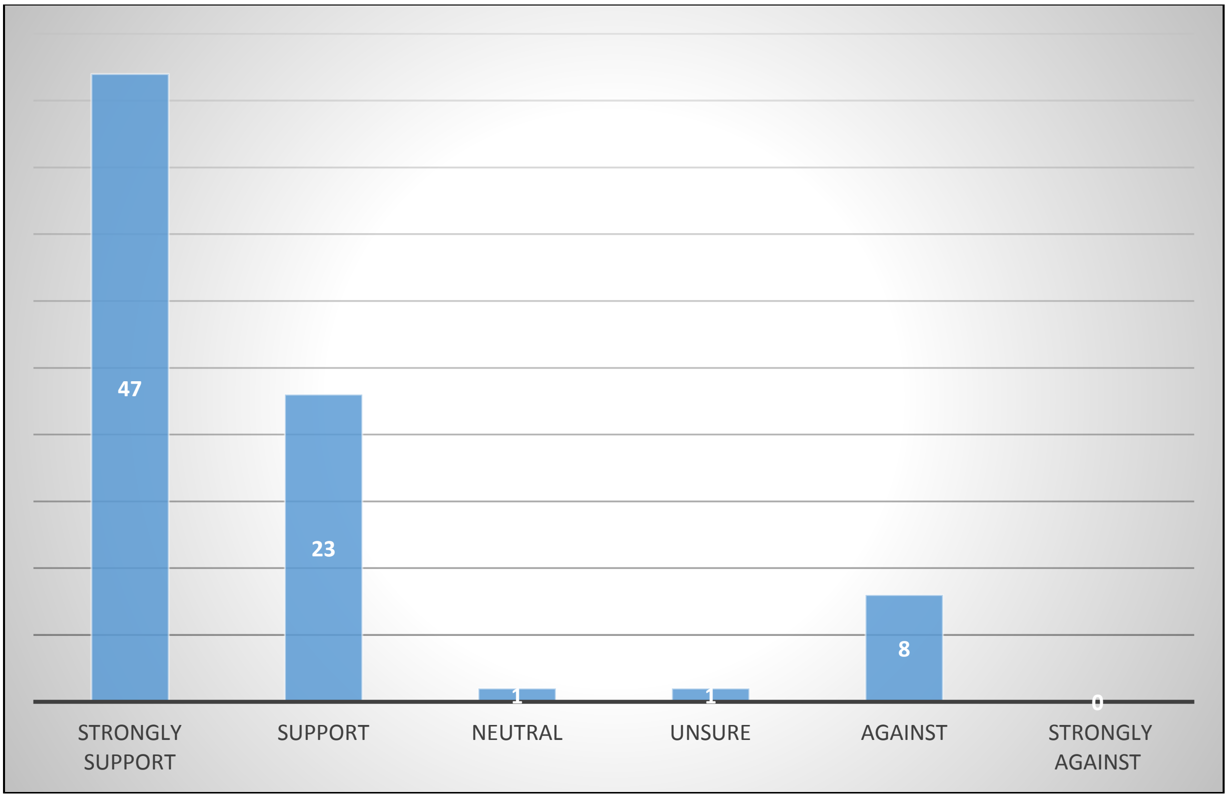


Plate 22 Community response to levee upgrade

Additional Considerations

As shown in **Figure 28**, peak flow velocities are predicted to exceed 2 m/s across the crest of earthen section of the existing Commercial Road levee during a 0.2% AEP flood. Velocities of this magnitude can be sufficient to erode/scour embankments even with good vegetation coverage. Accordingly, if a major flood was to occur that led to overtopping of the Commercial Road levee embankment, there is potential for scour of the levee which may lead to failure of the levee embankment. As discussed in Section 5.4.3, failure of the levee system has the potential to cause significant increases in flood levels and velocities behind the Commercial Road levee. Therefore, although raising of the levee is difficult to recommend from a benefit/cost and adverse flood impact perspective, options for reducing the potential for scouring/failure of the levee are considered worth pursuing.

It is considered that the potential for scouring/failure of the levee can be reduced by:

1) Remediation of levee sections that have settled with respect to time to reduce overtopping potential; and,
2) Ensuring that levee overtopping occurs in a controlled manner at a designated location (e.g., installation of a spillway).

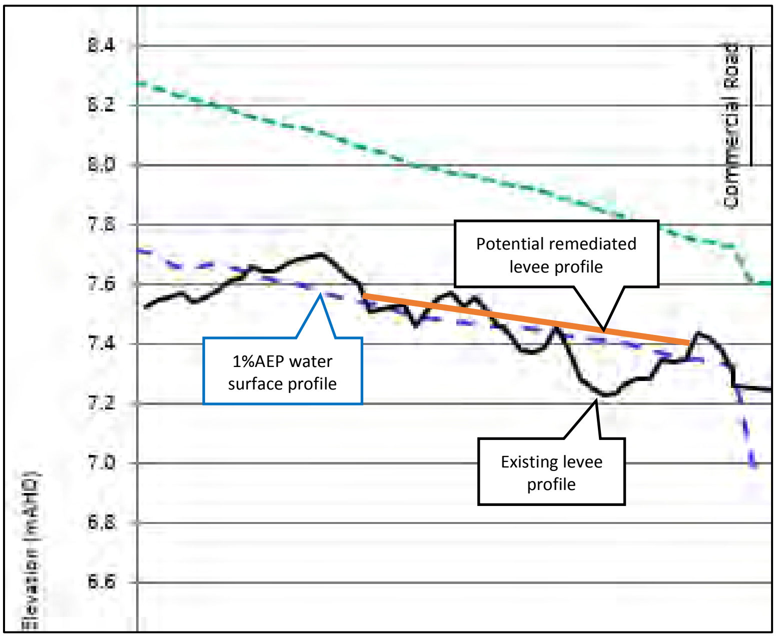
Each of these items is discussed in more detailed below.

Levee Remediation

As shown in **Figure 27**, the existing Commercial Road levee is predicted to initially overtop at two locations:

- Near Murwillumbah High School sports fields; and,
- Approximately 130 metres west of Commercial Road.

It appears the earthen embankment section of the Commercial Road levee may have differentially "settled" over time leading to the localised low/overtopping points outlined above. It is suggested that a detailed survey of the levee crest should be completed to identify areas where settlement may have occurred (most notably the low point located 130 metres west of Commercial Road), and remediation works could be completed to elevate these areas back to their original "design" levels. A suggested levee remediation profile is shown below and would involve elevating the existing low points in the levee by up to 0.3 metres. This remediation work should help to reduce the potential for overtopping at the current eastern overtopping point to prevent overtopping during the 1% AEP flood which, in turn, should reduce the potential for scour/failure at this location.



Spillway Construction

Although the levee remediation outlined above should help to reduce the frequency of overtopping at the remediation locations, it will not prevent the levee from overtopping during events equal to or greater than the 1% AEP flood. Therefore, it is still necessary to look at options that will allow water to overtop the levee in a safe and controlled manner that will help to ensure the integrity of the levee is maintained during large events.

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. In the context of Murwillumbah, this will require any overtopping to occur away from existing residential, commercial and industrial areas. Furthermore, the Handbook suggests that an appropriate overtopping location would allow for water to first spill into a "flood expansion zone" which would typically have a low population and low economic value. It suggested that the sporting fields located in the southern section of Murwillumbah would meet this requirement.

Based on consideration of these factors, it is considered that the current levee overtopping location near the Murwillumbah High School sports fields is a reasonable overtopping point as it is located a significant distance from existing development and would allow water to first "spill" across areas of open space. However, this location is not specifically designed to cater for overtopping and, therefore, the potential for the integrity of the levee and sporting fields to be maintained during a future flood cannot be guaranteed.

Therefore, it is suggested that works could be completed in the vicinity of the existing sporting fields to implement an official levee spillway. This would require design and construction of the following components:

- Spillway crest;
- A slope to carry water from the spillway over the landward side of the levee;
- A "stilling basin" at the base of the slope that diffuses the energy of the spilled water;

The design of the spillway is beyond the scope of the current study. However, it is recommended that that the following design recommendations are made:

- The spillway elevation should be located close to the elevation of the current sports fields so that the potential for adverse flood impacts is minimised;
- Installation of a water level gauge on the spillway should be explored so that emergency services and Council can be automatically notified when levee overtopping occurs;

Option: Option A – Levee Raising
Recommendation: Levee raising is not recommended for implementation. However, the potential to remediate areas of the Commercial Road earthen levee that have settled should be investigated along with the potential to install a formalised spillway

6.4.2 Option B - New and Upgraded Pump Systems

Description of Option

This option would involve upgrading the existing Lavender Creek and CBD pump stations and inclusion of new pump systems to drain the areas behind the East Murwillumbah and Dorothy Street Levees.

The extent of works that would be completed to implement Option B is shown in **Figure H2** in **Appendix H** and would include:

- Duplication of the existing Wharf Street pump to double the pumping capacity from this section of the Murwillumbah CBD.
- Inclusion of an additional "low flow" pump to supplement the existing Lavender Creek pump system (equivalent in capacity to the existing Wharf St pump system). The pump would start pumping from Lavender Creek at a lower level than the current pumps to assist in more efficiently draining frequent rainfall events. If flood levels in Lavender Creek continue to increase (during more severe rainfall events), the current pump system would operate as per usual.
- A new pump system near George Street (just east of York Street) to assist in draining East Murwillumbah. It was assumed that the pump system would provide a peak flow capacity of 2 m^3/s and would start to operate once the water depth upstream of George Street exceeds 1 metre.

- A new pump system to assist in draining the area behind the Dorothy Street levee. It was assumed the Dorothy Street pump system would provide a peak flow capacity of 2 m^3/s and would start to operate once the water depth upstream of the levee exceeded 0.8 metres.

Hydraulic Benefits

The TUFLOW model was updated to include the new and upgraded pump systems and was used to re-simulate each design flood. Flood level difference maps were prepared for the 20% AEP and 1% AEP floods and are presented in **Plates 23** and **25** respectively. Time of inundation difference mapping was also prepared to quantify how the new pump systems may reduce the duration of inundation. Time of inundation difference mapping is presented in **Plates 24** and **26.**

Stage hydrographs for the 1% AEP flood were also extracted at various locations behind the levee with the pump upgrades and are presented in **Appendix K**.

The change in number of buildings exposed to above floor inundation was also calculated based on the results of the design flood simulations. This information is summarised in **Table 14**.

Plates 23 and **25** shows that the proposed pump systems provides some significant reduction in flood levels behind the Dorothy Street levee during both the 20% AEP and 1% AEP floods. Flood level reductions of at least half a metre are anticipated behind the levee during these events.

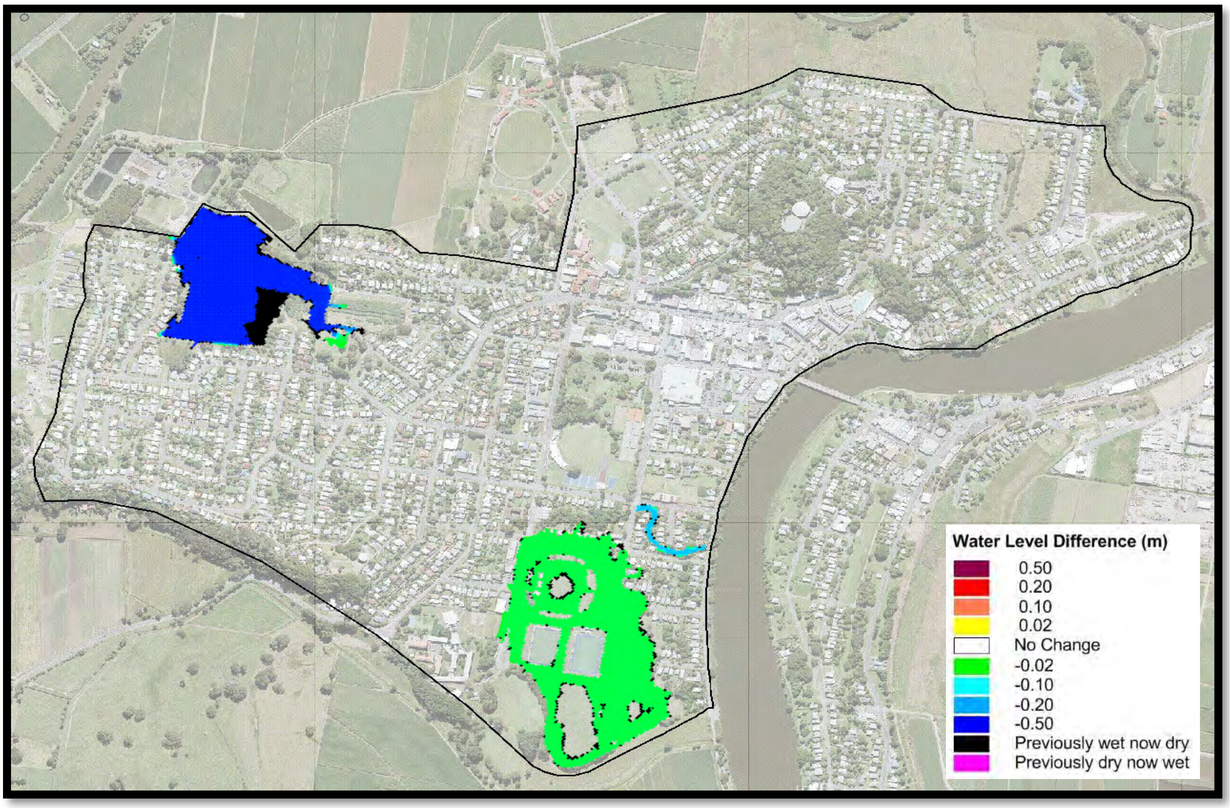


Plate 23 Peak 20% AEP Flood Level Difference Mapping for New/Upgraded pump

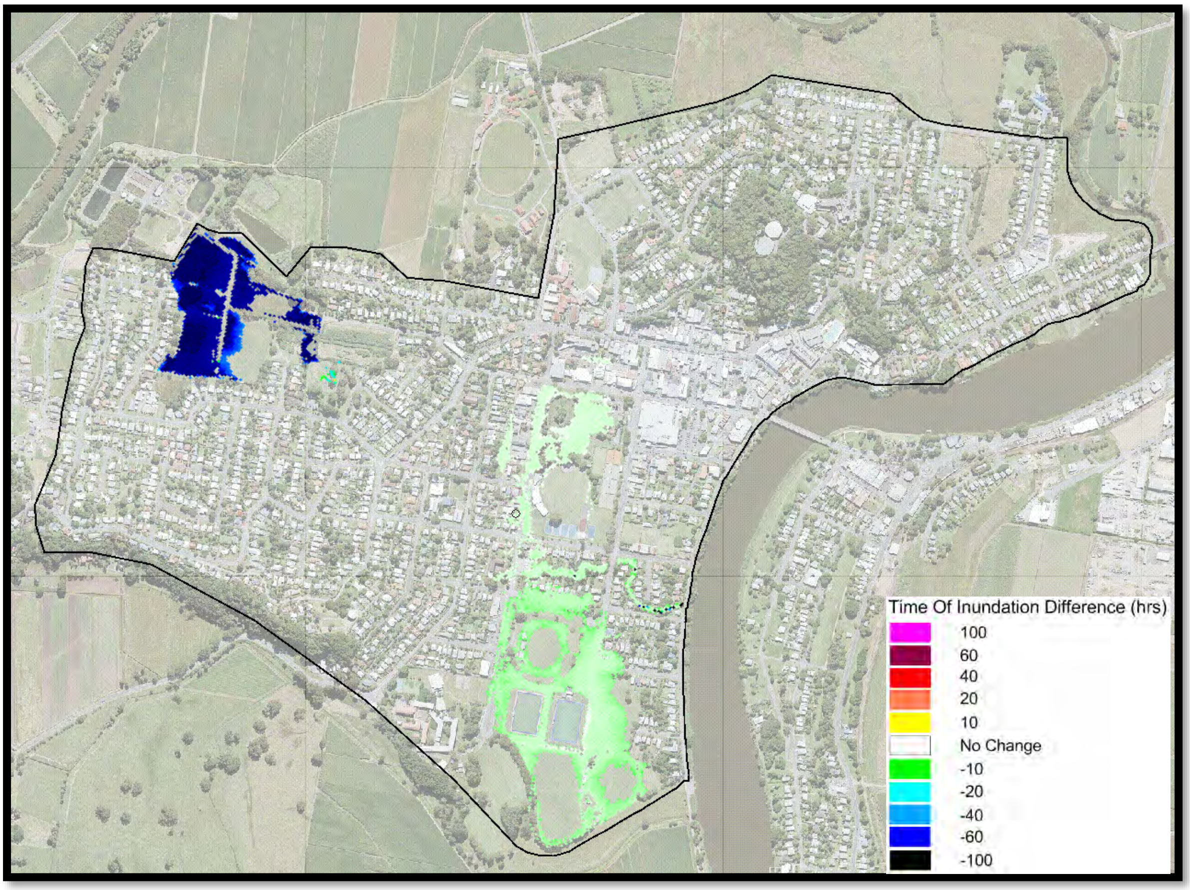


Plate 24 20% AEP Flood Time of Inundation Difference Mapping for New/Upgraded pump

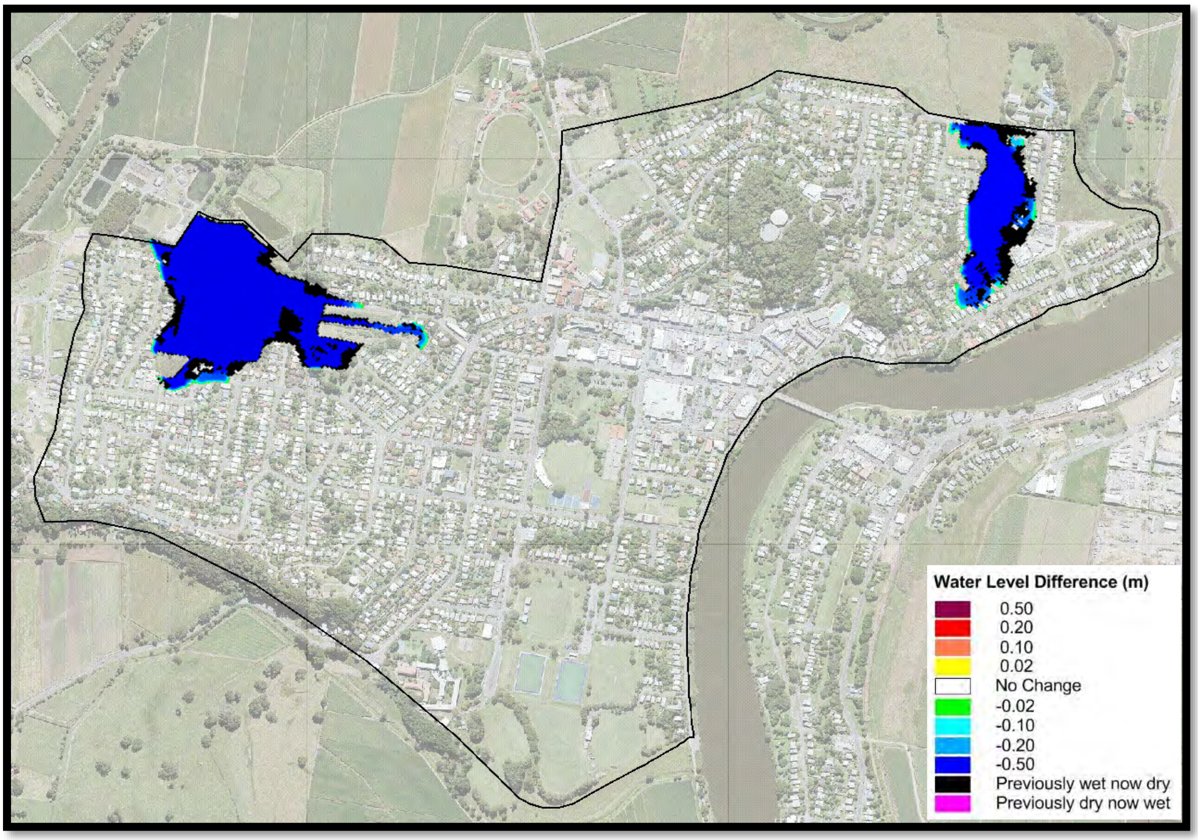


Plate 25 Peak 1% AEP Flood Level Difference Mapping for New/Upgraded pump

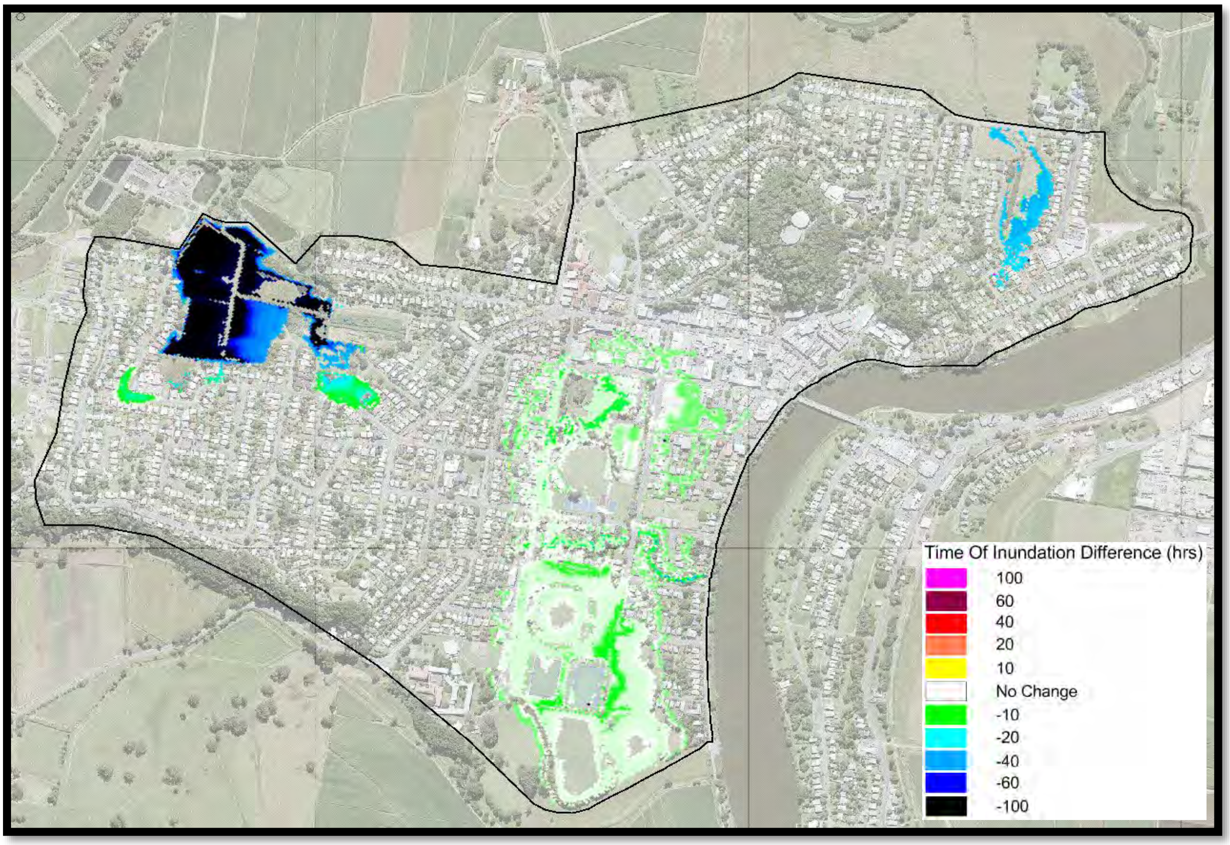


Plate 26 Peak 1% AEP Flood Time of Inundation Difference Mapping for New/Upgraded pump

Table 14 Change in Number of Buildings Inundated Above Floor Level with upgraded Pump System

Design Flood	Change in number of buildings with above floor inundation		
	Residential	Commercial/ Industrial	Total Number
20% AEP	0	0	0
5% AEP	0	0	0
1% AEP	0	-1	-1
0.2% AEP	-1	0	-1

Significant reductions in flood levels are also predicted behind the East Murwillumbah levee during the 1% AEP flood. Negligible reductions are anticipated across this area during the 20% AEP event as the depths of inundation are not significant enough to trigger the operation of the pump.

The upgraded Wharf Street pump system is predicted to provide negligible flood level reductions across the CBD. This indicates that the current pump arrangement (which comprises a “sump” connected by a series of pipes) does not lend itself well to a simple increase in pump capacity (the limit appears to the pipes that feed water to the pump system). Therefore, it is likely the existing pump system would need to be supplemented with a completely independent pump system to provide a more significant beneficial impact.

Plates 23 and **25** also show that the revised Lavender Creek pump configuration will afford some flood level reductions south of Lavender Creek. However, negligible reductions are predicted during larger events that overtop the levee. This is primarily associated with the additional pump being overwhelmed during events that overtop the level.

Plates 24 and **26** shows that the pump system will assist in more rapidly draining the areas behind the levee should inundation occur. The most significant reductions in inundation times are predicted behind the Dorothy Street levee where inclusion of a high capacity pump system will reduce inundation time by around 100 hours during the 1% AEP flood and 70 hours during the 5% AEP flood. Reductions in inundation times of about 30 hours are predicted behind the Murwillumbah East levee and reductions of between 2 and 12 hours are predicted behind the Commercial Road levee during the 1% AEP flood. Draining the area behind each levee more rapidly will assist in allowing flood recovery efforts to commence sooner, so are considered an important factor when evaluating options.

Economic Benefits

It is expected that the pump upgrades would cost approximately $2.4 million to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

A revised damages assessment was completed based on the results of the revised simulations. This determined that average annual flood damages could be expected to reduce by $10,000 per annum. This would provide a total reduction in flood damage costs of $141,000 over the 50-year design life of the pump system. This provides a preliminary benefit-cost ratio (BCR) of 0.05, which indicates that the costs associated with implementation of the pump upgrades far outweigh the reduction in flood damage costs.

Although the economic benefits of the combined pump upgrades were low, the Dorothy Street pump system afforded some notable reductions in flood levels. Therefore, a separate benefit cost assessment was completed for the Dorothy Street pump insolation. This determined that the cost to implement the Dorothy Street pump would be about $980,000. If the Dorothy Street pump was implemented it is predicted to reduce average annual damages by $3,000 per annum, which would provide a total reduction in flood damages of $42,300 over the 50-year design life of the pump system. This provides a preliminary benefit-cost ratio of 0.04. Accordingly, consideration of the Dorothy Street levee in isolation does not afford any improvement in the BCR.

Community Acceptance

The pump systems were generally well supported by the community with the majority of the community “strongly supporting” the option (refer **Plate 27**).

Emergency Response Benefits

As discussed, installation of a new or additional pump system will assist in draining areas behind the levee more rapidly so flood recovery efforts can commence sooner. Stage hydrographs with the pump system in place are included in **Appendix K** and confirms that the pumps would provide a significant reduction in the time it takes to drain the area contained behind each levee.

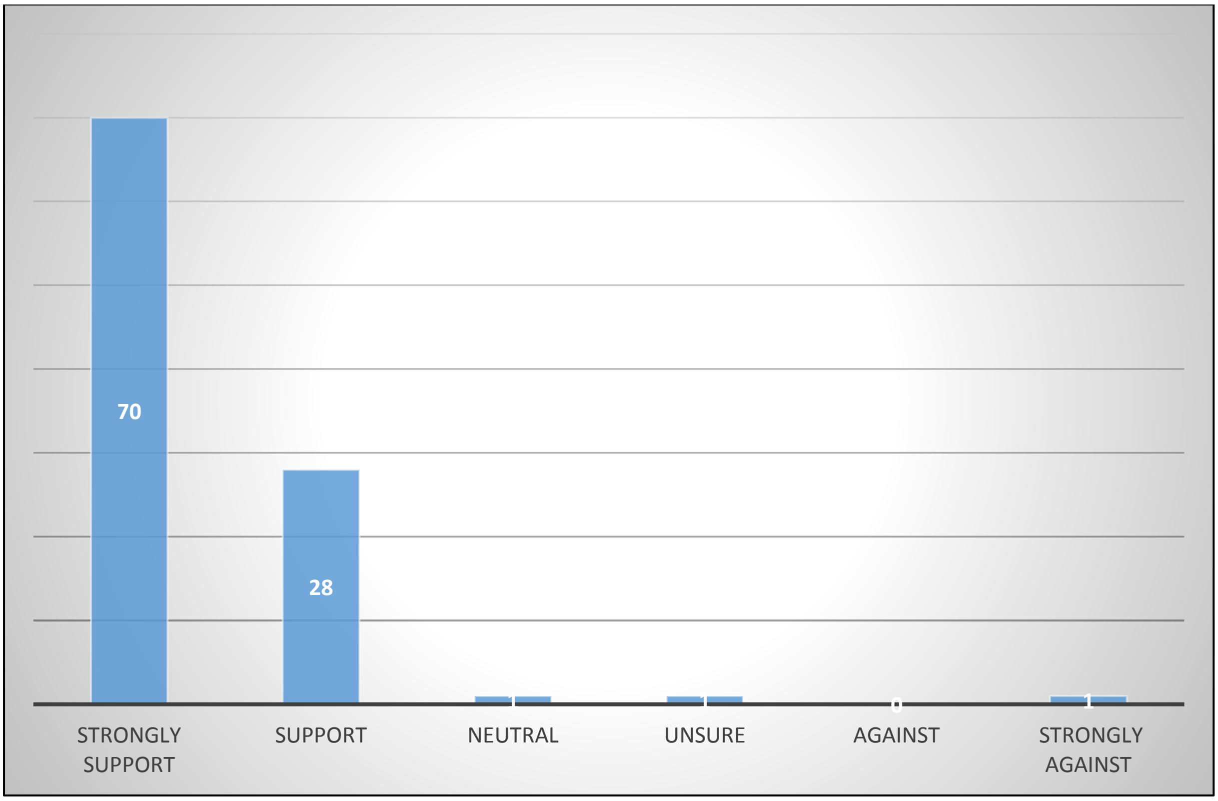


Plate 27 Community response to upgraded pump systems

The pump systems will also assist in lowering flood levels in areas behind the levee, which may provide additional time for evacuation. A review of the time series outputs from the modelling shows that roads behind the Commercial Road levee would remain trafficable for 30 minutes to 1 hour longer during the 1% AEP flood relative to current conditions. Although this is a fairly minor improvement, it could prove valuable during a future flood.

Option: Option B – New and Upgraded Pump System
Recommendation: Dorothy Street levee pump system recommended for implementation

6.4.3 Option C - Proudfoots Lane Pump System

Description of Option

This option involves the installation of a new pump system at the “sag” point in Proudfoots Lane. The pump would assist in draining this section of the CBD and would also assist in draining the Knox park area.

The design concept for this option is shown in **Figure H3** in **Appendix H** and includes the following components:

- Construction of a new “sump” at the sag point in Proundfoot Lane.
- Provision of two submersible pumps in the sump capable of a peak combined flow rate of $2m^3/s$.

- Installation of a new 600mm diameter pipe from Knox Park to the new pump system. The pipe would flow under gravity from Knox Park when water levels in Knox Park become elevated.
- Installation of new 375mm diameter outlet pipe from the pump system to the rear of the Mount St Patrick College grounds.

As outlined above, the pump would discharge to the Mount St Patrick College grounds. This location was selected as it requires a relatively short length of pipe and design flood levels at this location are significantly lower than the Tweed River (i.e., pump does not need to push water "uphill"). However, the significant variations in terrain along this alignment will likely require boring, which will significantly add to the construction costs.

Hydraulic Benefits

The TUFLOW model was updated to include the new pump system. The updated TUFOW model was used to re-simulate the 20%, 5%, 1% and 0.2% AEP events.

Flood level and time of inundation difference mapping was prepared for the 20% AEP and is presented in **Plates 28** and **29**. Difference mapping for the 1% AEP flood are presented in **Plates 30** and **31**.

The change in number of building subject to over floor inundation was also calculated and is presented in **Table 15**.

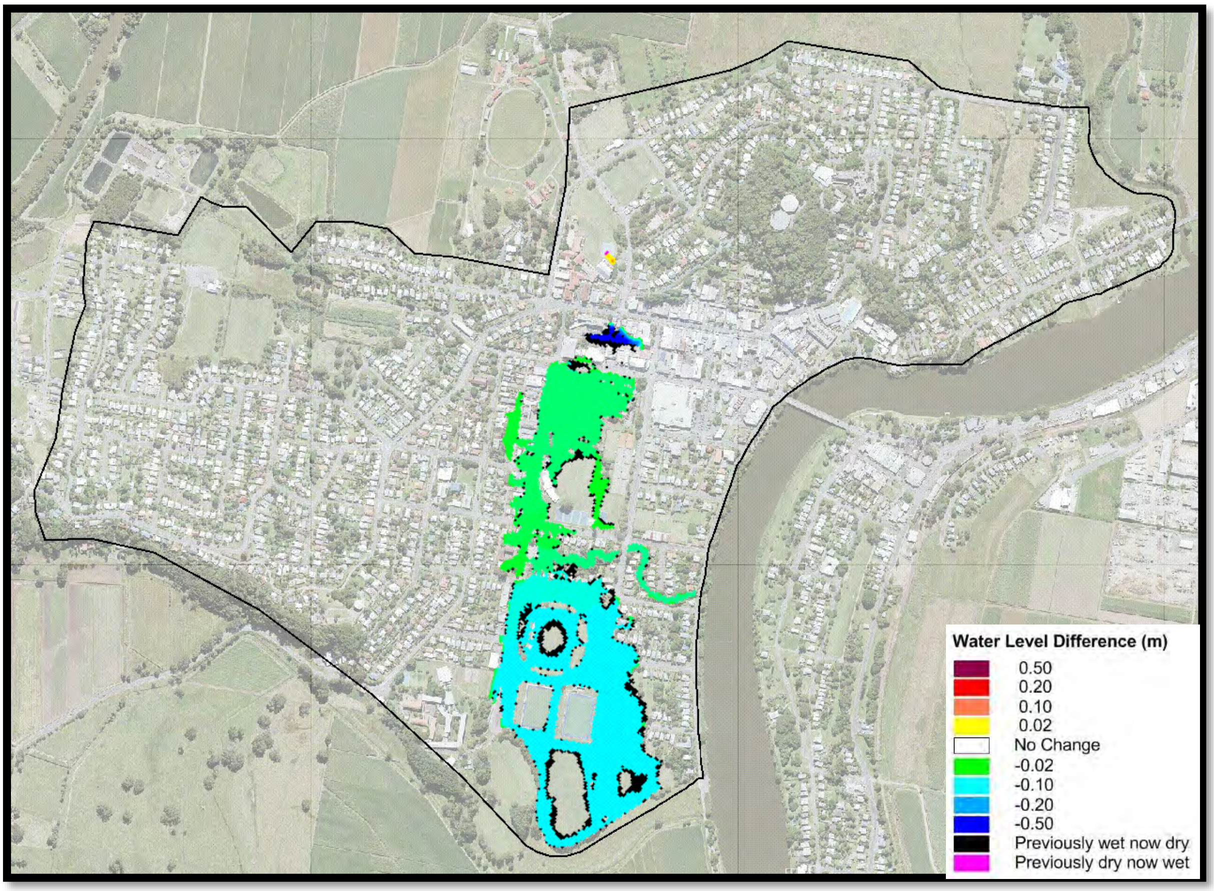


Plate 28 Peak 20% AEP Flood Level Difference Mapping for Proudfoot Lane Pump

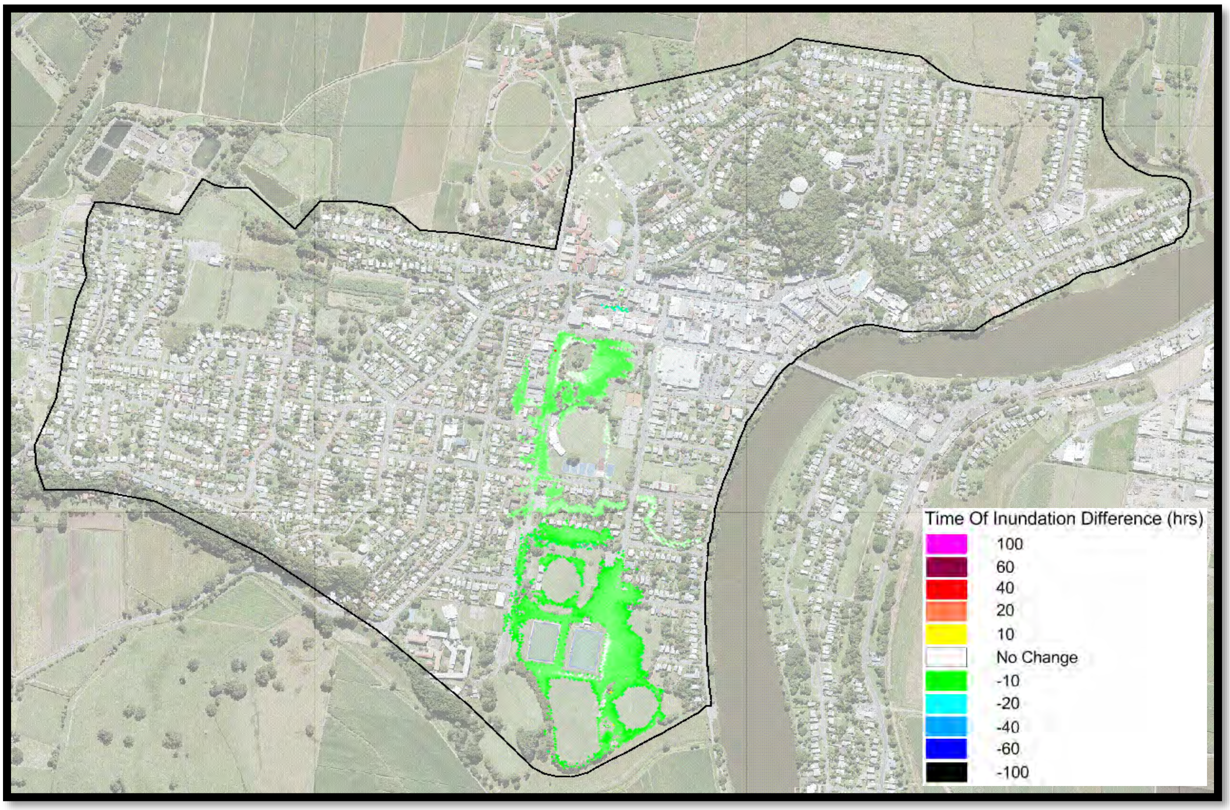


Plate 29 Peak 20% AEP Flood Time of Inundation Difference Mapping for Proudfoot Lane Pump

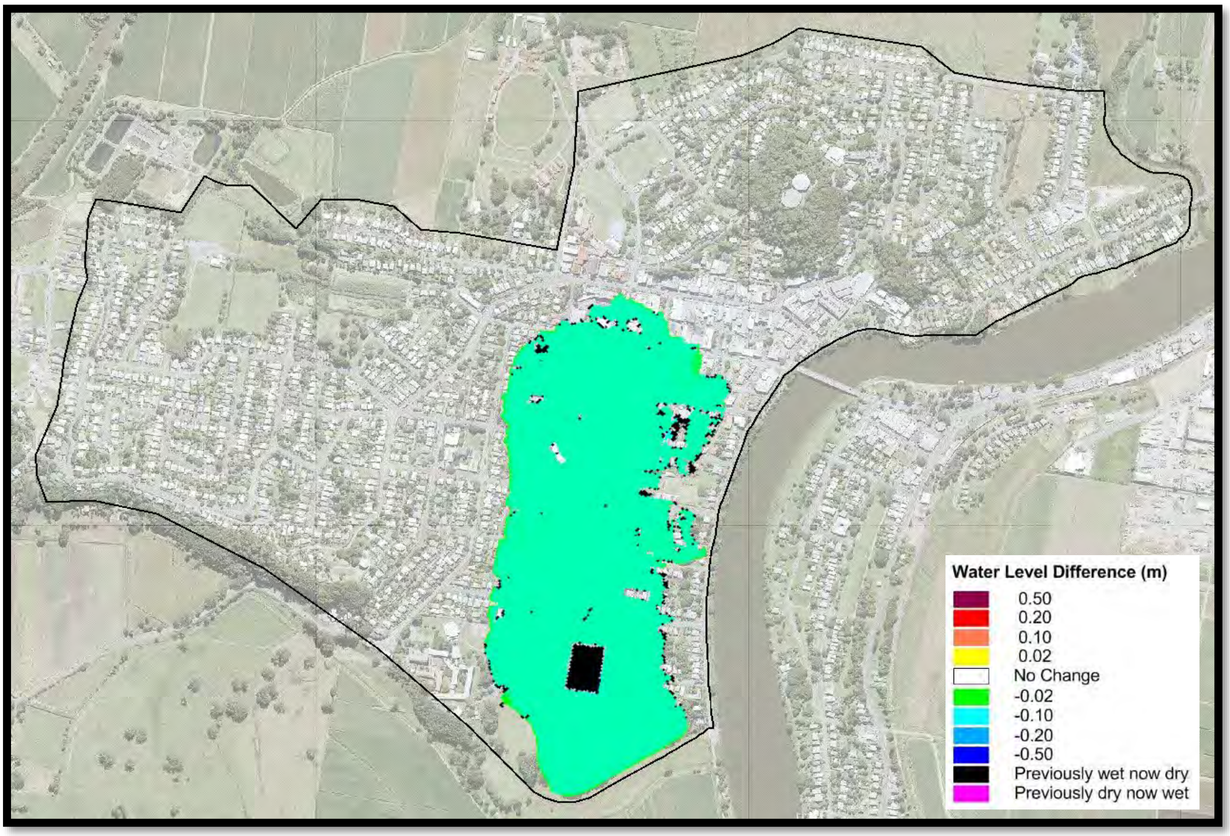


Plate 30 Peak 1% AEP Flood Level Difference Mapping for Proudfoot Lane Pump

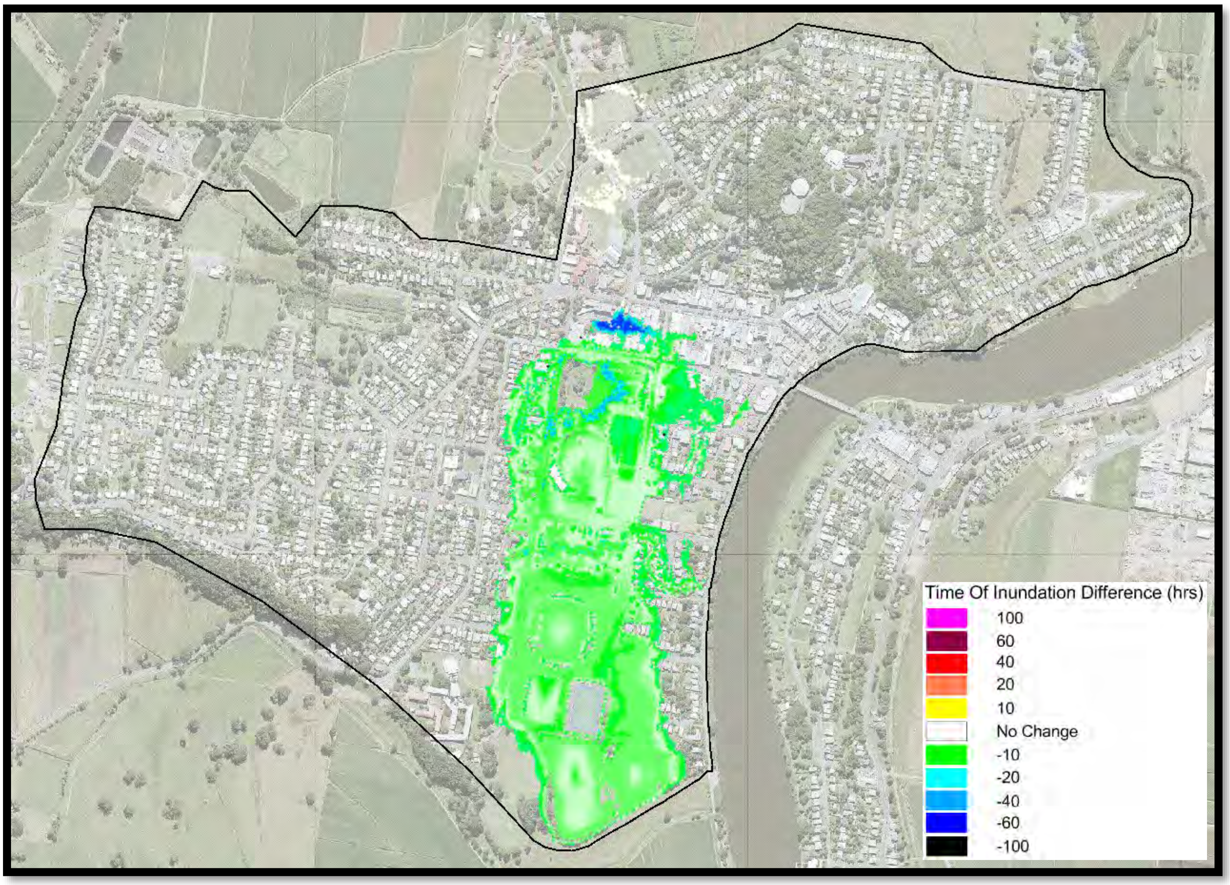


Plate 31 Peak 1% AEP Flood Time of Inundation Difference Mapping for Proudfoot Lane Pump

Table 15 Change in Number of Buildings Inundated Above Floor Level with Proudfoots Lane Pump

Design Flood	Change in number of buildings with above floor inundation		
	Residential	Commercial/ Industrial	Total Number
20% AEP	0	0	0
5% AEP	0	0	0
1% AEP	0	-1	-1
0.2% AEP	0	0	0

Plates 28 and **30** shows that the Proudfoot Lane pump system will reduce flood levels during both the 20% AEP and 1% AEP events. Flood level reductions of up to 0.5 metres are predicted in Proudfoots Lane during the 20% AEP event. Reductions of up to 0.1 metres are predicted to the south of Proudfoots Lane (including Knox Park). Flood level reductions during the 1% AEP flood are typically less than 0.05 metres.

Plates 29 and **31** show that the Proudfoots Lane pump system will also provide some reductions in the duration of inundation behind the Commercial Road levee. During the 20% AEP flood, the inundation time reductions are predicted to be about 5 hours. During the 1% AEP flood reductions in inundation times of between 10 and 20 hours are predicted across the lower lying areas behind the Commercial Road levee. Reductions of up the 48 hours are predicted in Proudfoot Lane.

Economic Benefits

It is expected that the pump system would cost approximately $2.7 million to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

A revised damages assessment was completed based on the results of the revised simulations. This determined that average annual flood damages could be expected to reduce by $10,000 per annum. This would provide a total reduction in flood damage costs of $140,000 over the 50-year design life of the pump system. This provides a preliminary benefit-cost ratio (BCR) of 0.05, which indicates that the costs associated with implementation of the pump upgrades far outweigh the reduction in flood damage costs.

Community Acceptance

The Proudfoot pump system was generally well supported by the community with the majority of the community "strongly supporting" the option (refer **Plate 32**).

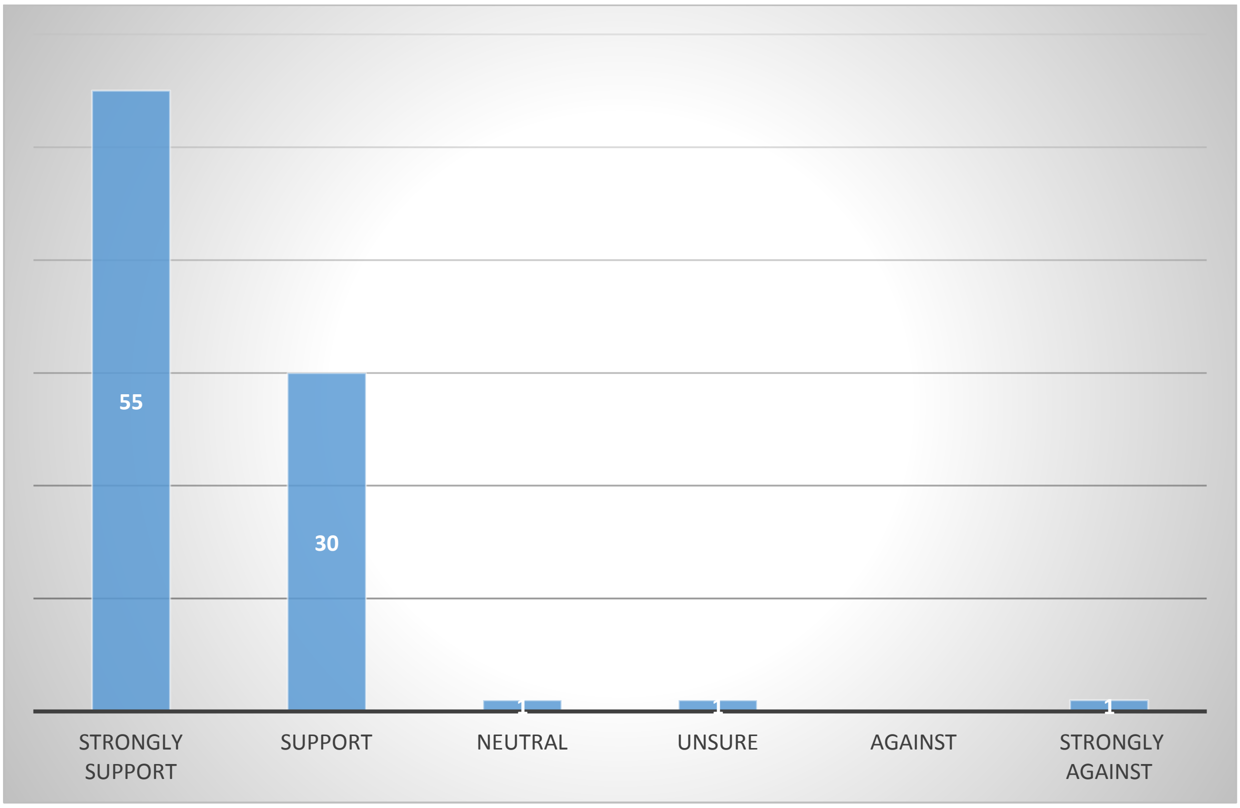


Plate 32 Community response to Proudfoots Lane pump system

Emergency Response Benefits

As discussed, installation of a new or additional pump systems will assist in draining areas behind the levee more rapidly so flood recovery efforts can commence sooner.

The pump systems will also assist in lowering flood levels in areas behind the levee, which may provide additional time for evacuation. A review of the time series outputs from the modelling shows that roads adjoining Knox park would remain trafficable for up to 1 hour longer during the 1% AEP flood relative to current conditions.

Option: Option C – Proudfoots Lane Pump System
Recommendation: Provides some notable benefits. However, high cost means this option is unlikely to be viable

6.4.4 Option D - Regrading of William Street and Wharf Street

Description of Option

This option involves regrading of roadways to reduce ponding depths and redirect overland flows away from existing properties. The location identified for regrading are shown in **Figure H4** in **Appendix H** and includes:

- Wharf St from near the intersection of Commercial Rd towards Tumbulgum Rd. the regrading would aim to direct overland flows from the existing "sag" point near the intersection of Wharf Street and Commercial Roads east towards the levee.
- Regrading of the existing "sag" point immediately east of Dorothy St. The regrading would aim to direct overland flow east along William Street and ultimately between number 51 and 53 William Street.

Hydraulic Benefits

The roadway regrading was incorporated within an updated TUFLOW model and the updated model was used to re-simulate each design flood. Flood level difference mapping was prepared for the 20% AEP and 1% AEP design floods and is shown in **Plates 33** to **34**.

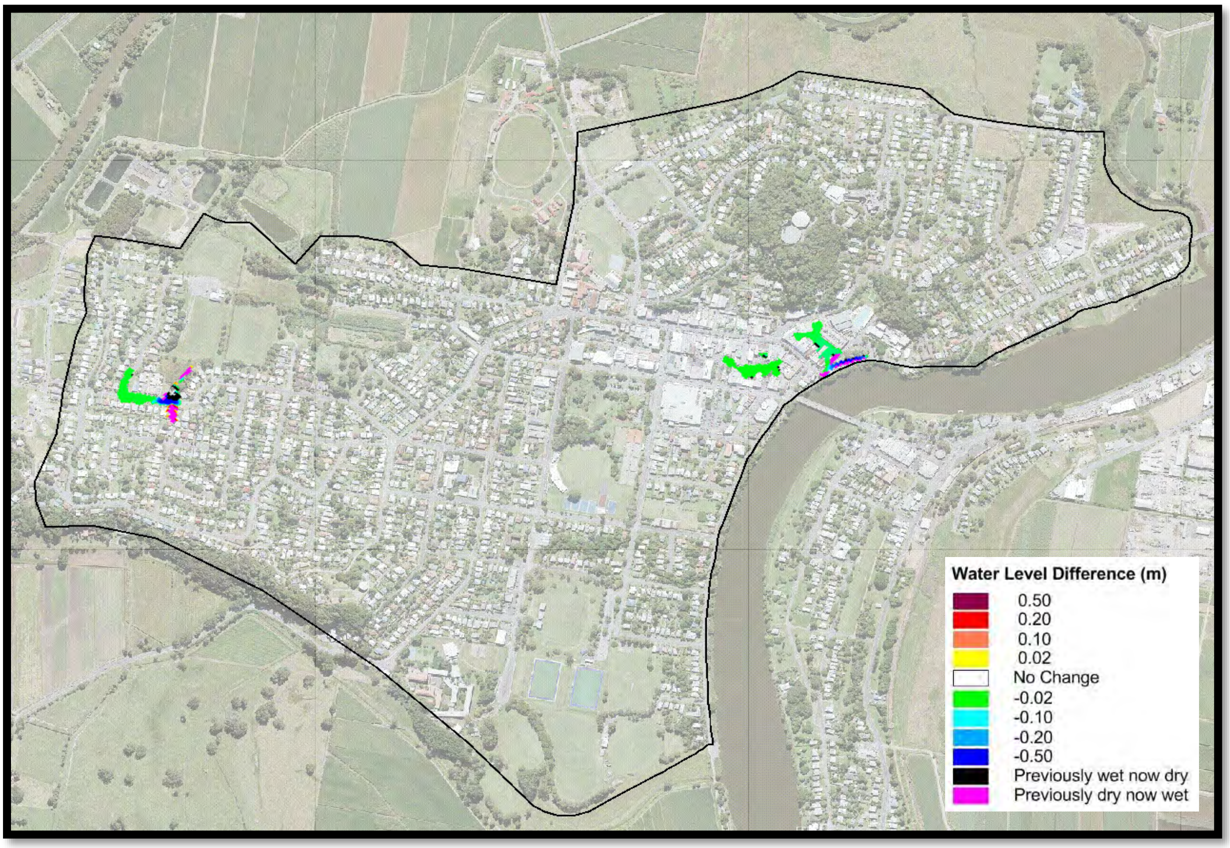


Plate 33 Peak 20% AEP Flood Level Difference Mapping for Road Regrading

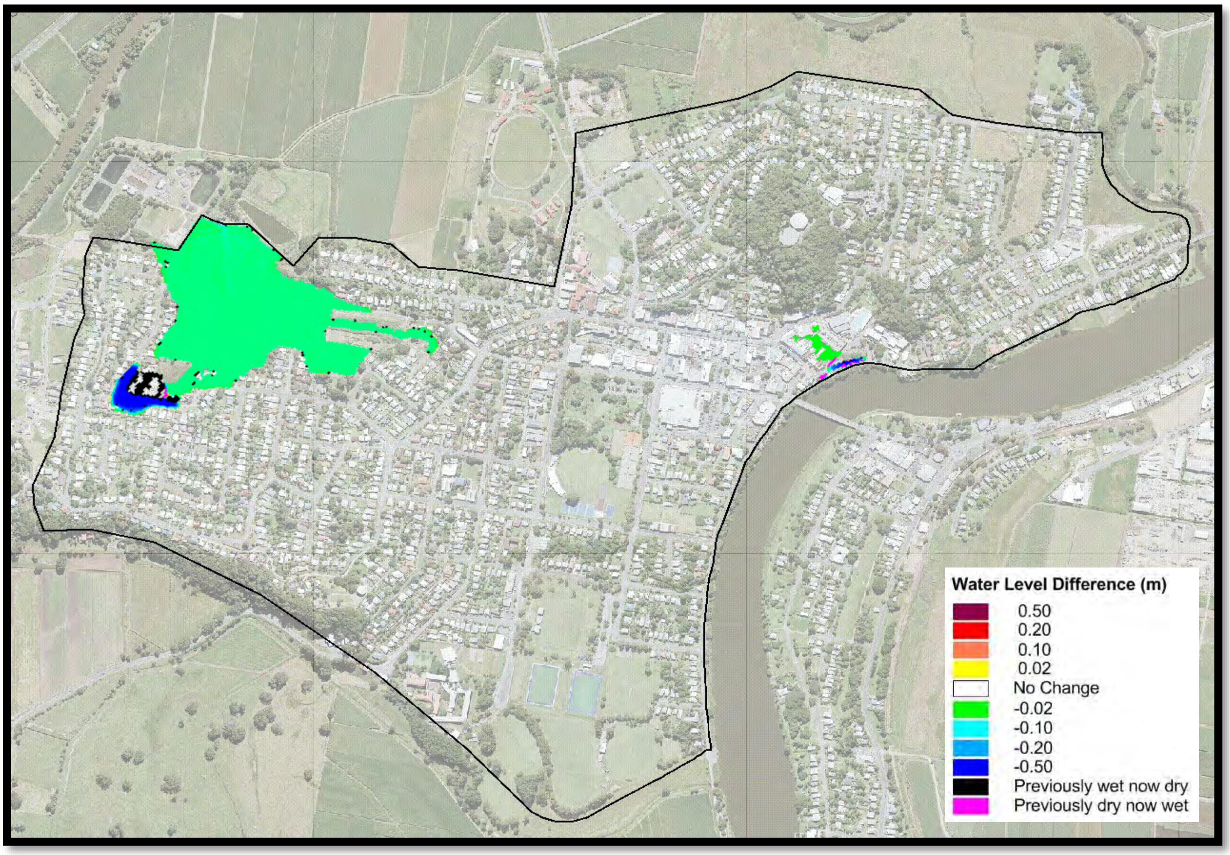


Plate 34 Peak 1% AEP Flood Level Difference Mapping for Road Regrading

The change in number of buildings exposed to above floor inundation was also calculated based on the results of the design flood simulations. This information is summarised in **Table 14**.

Table 16 Change in Number of Buildings Inundated Above Floor Level with Road Regrading

Design Flood	Change in number of buildings with above floor inundation		
	Residential	Commercial/ Industrial	Total Number
20% AEP	0	-2	-2
5% AEP	0	0	0
1% AEP	0	0	0
0.2% AEP	0	0	0

Plates 33 to **34** show that the William Street regarding affords some significant reductions in flood levels in the vicinity of Dorothy Street. In particular, reductions approaching 0.5 metres are predicted during the 1% AEP event.

The Wharf Street regrading is also predicted to reduce existing flood levels in the vicinity of the Wharf Street and Commercial Road intersection. Flood level reductions are also predicted to extend into Proudfoot's Lane during the 20% AEP event. The flood level reductions that are predicted during the 20% AEP flood are sufficient to result in 2 fewer commercial properties being exposed to above floor inundation.

Economic Benefits

It is expected that the road regrading would cost approximately $1.4 million to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

A revised damages assessment was completed based on the results of the revised simulations. This determined that average annual flood damages could be expected to reduce by $2,000 per annum. This would provide a total reduction in flood damage costs of $26,000 over a 50-year period. This provides a preliminary benefit-cost ratio (BCR) of 0.02, which indicates that the costs associated with implementation of the pump upgrades far outweigh the reduction in flood damage costs.

Community Acceptance

The regrading was generally well supported by the community with the majority of the community "strongly supporting" the option (refer **Plate 35**).

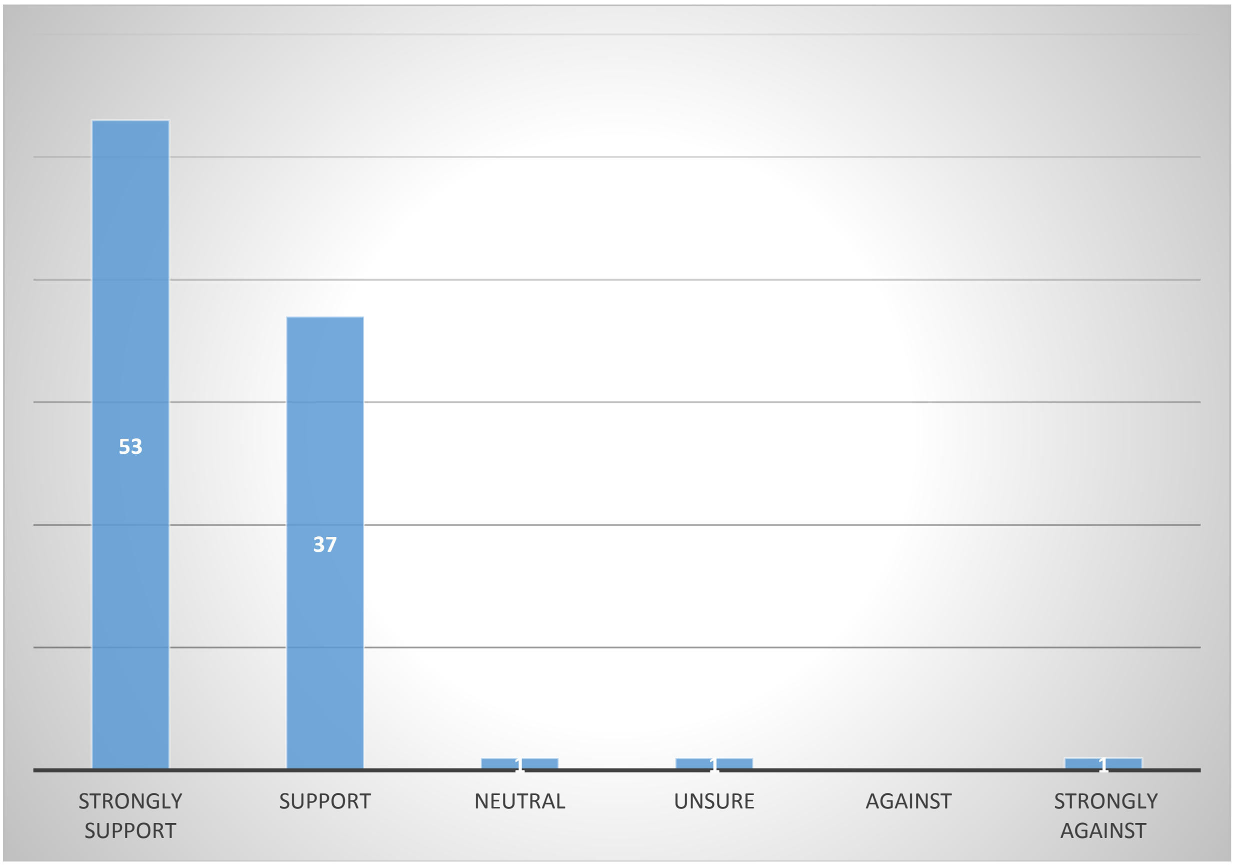


Plate 35 Community response to road regrading

Emergency Response Benefits

The regrading would assist in reducing ponding depths in William Street and Wharf Street. Although this will provide additional time for travel along William Street, alternate, elevated evacuation routes already exist. The Wharf Street regrading will allow the intersection of Wharf Street and Commercial Road to remain trafficable for an additional 30-minutes. Accordingly, the regrading will only provide a small emergency response improvement.

Option: Option D – Regrading of William Street and Wharf Street
Recommendation: Not recommended for implementation

6.4.5 Option E - Drainage Upgrades

Description of Option

This option includes duplication of a number of existing pipes and installation of new pipes and pits at a number of locations. The extent of the drainage upgrades are shown in **Figure H5** in **Appendix H** and include:

- Duplication of the existing stormwater pipe system along Nullum Lane from Price Street through to Nullum Street.
- Duplication of all stormwater pipes in Proudfoots Lane between Brisbane Street and Nullum Street, including the pipes draining south to Wollumbin St.
- Duplication of the existing stormwater pipe system near the William Street/ Dorothy Street intersection and installation of an additional pipe between number 51 and 53 William Street (pipe system discharges into the playing fields to the north).

Hydraulic Benefits

The stormwater upgrades were included in a modified TUFLOW model and the modified TUFLOW model was used to simulate the 20%, 5%, 1% and 0.2% AEP events. Flood level difference mapping was prepared for the 20% AEP and 1% AEP and is presented in **Plate 36** and **37**.

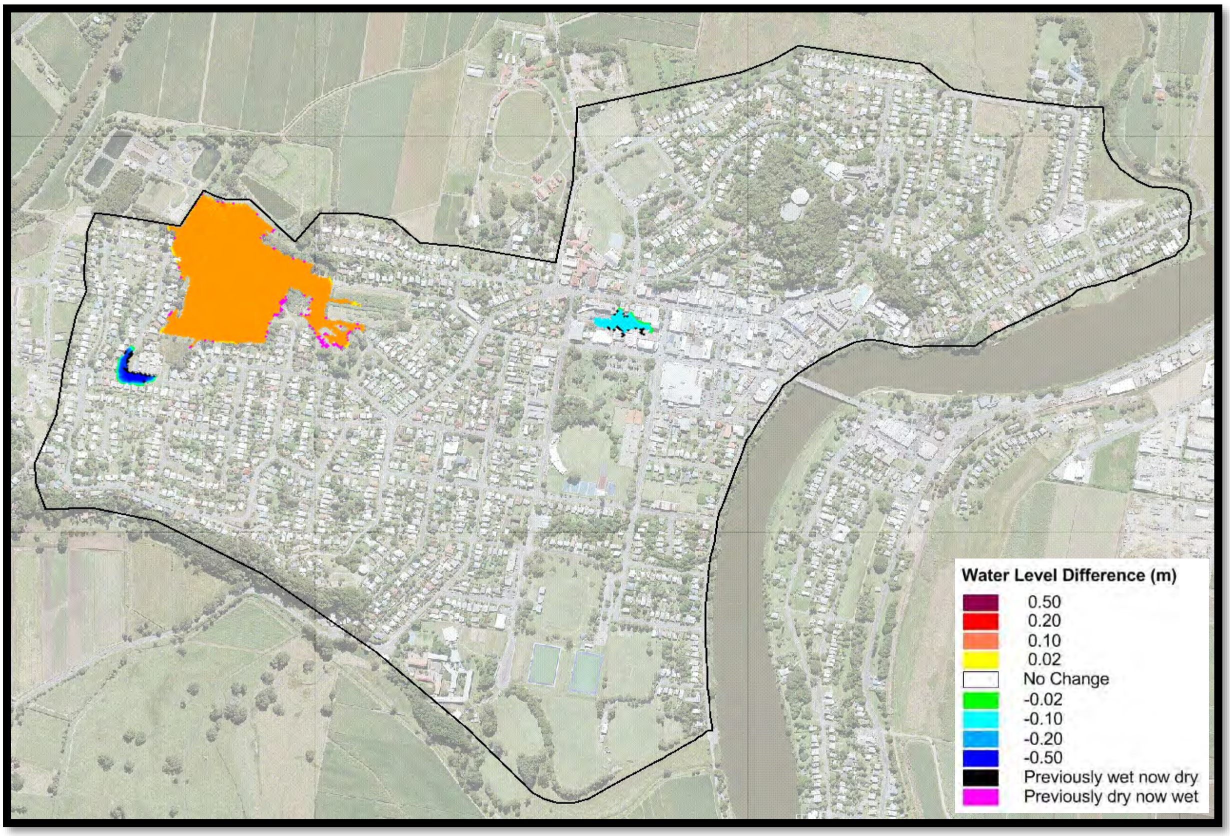


Plate 36 Peak 20% AEP Flood Level Difference Mapping for Drainage Upgrades

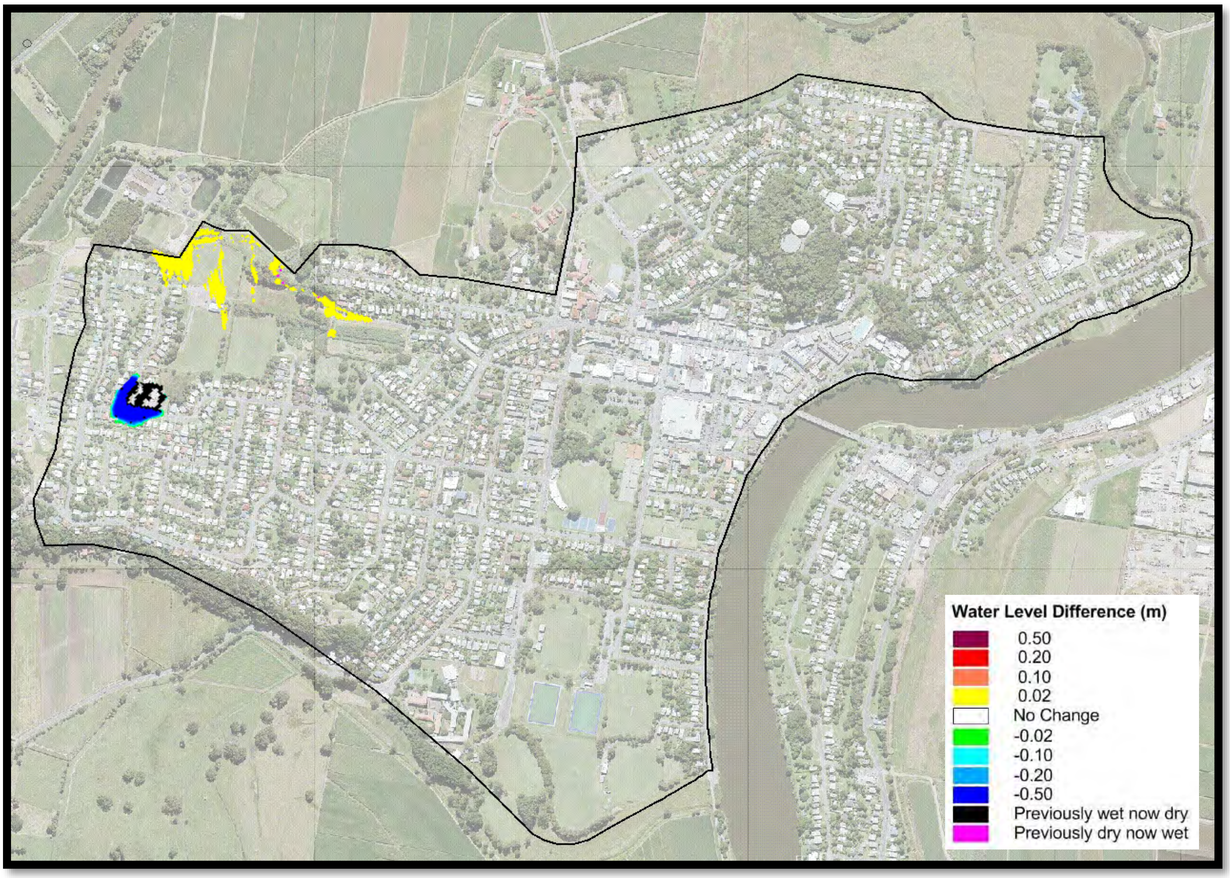


Plate 37 Peak 1% AEP Flood Level Difference Mapping for Drainage Upgrades

The change in number of building subject to over floor inundation was also calculated and is presented in **Table 15**.

Table 17 Change in Number of Buildings Inundated Above Floor Level with Drainage Upgrades

Design Flood	Change in number of buildings with above floor inundation		
	Residential	Commercial/ Industrial	Total Number
20% AEP	0	0	0
5% AEP	0	0	0
1% AEP	0	0	0
0.2% AEP	0	0	0

Plate 36 shows that the drainage upgrades are predicted to reduce 20% AEP flood levels in William Street by over 0.5 metres. However, the additional flow diverted to the playing fields to the north is predicted to increase flood levels by around 0.08 metres.

Plate 36 also shows some small reductions in flood levels in Proudfoot Lane (~0.1 metres). No reductions in flood levels are predicted in Nullum Lane.

Plate 37 shows that the William Street drainage upgrades are also predicted to provide some significant reductions in 1% AEP flood levels (~0.6 metres). No reductions in 1% AEP flood levels are anticipated in Nullum Lane or Proudfoots Lane.

Economic Benefits

It is expected that the drainage upgrades would cost approximately $880,000 to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

A revised damages assessment was completed based on the results of the revised simulations. This determined that average annual flood damages could be expected to increase by $1,000 per annum. This would provide a total increase in flood damage costs of $7,000 over a 50-year period and a negative BCR. Accordingly, this option does not afford a financial benefit.

Community Acceptance

The drainage upgrades were generally well supported by the community with the majority of the community "strongly supporting" the option (refer **Plate 38**).

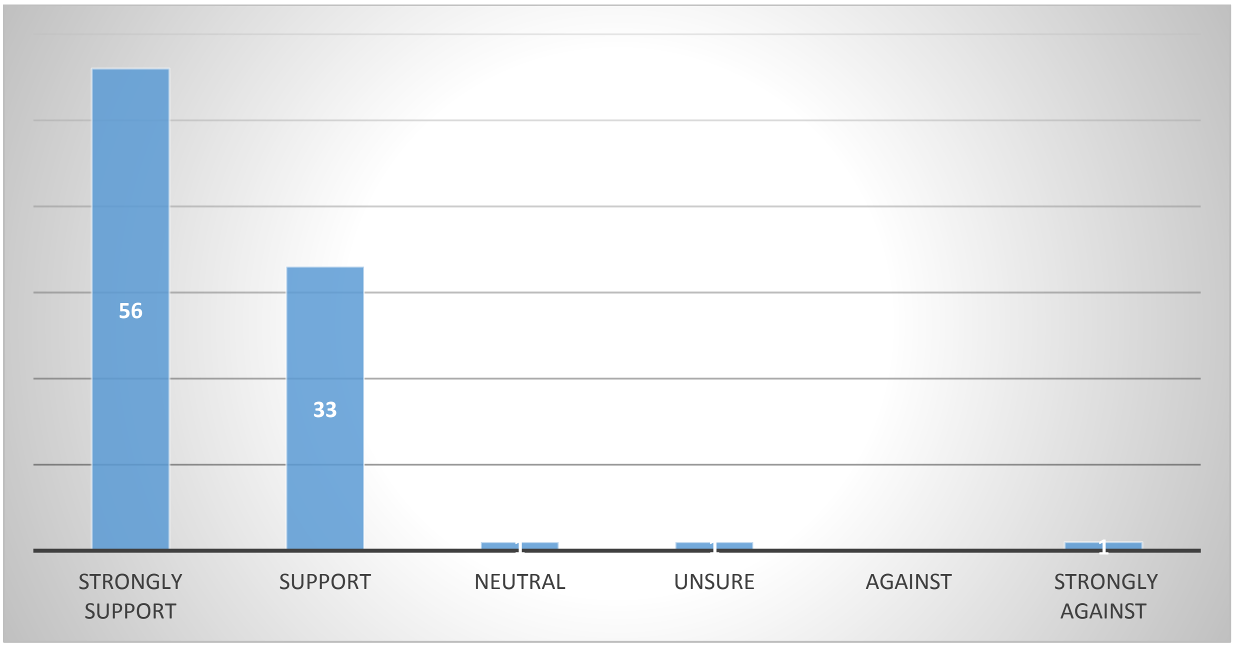


Plate 38 Community response to drainage upgrades

Emergency Response Benefits

The drainage upgrades would assist in reducing ponding depths, which would provide improved traffic access across the western sections of Murwillumbah. However, as a number of alternative evacuation routes exist, the emergency response improvements would be minimal. Negligible improvement to roadway inundation times would be afforded in Nullum Lane and Proudfoots Lane.

Option: Option E – Drainage Upgrades
Recommendation: Not recommended for implementation

6.4.6 Option F - Commercial Road Levee Gate Modifications

Description of Option

As discussed in Section 2.4.1 the concrete panel wall section of the Commercial Road levee includes gated openings that are manually closed and sealed immediately prior to floods at Murwillumbah. This option would look at modifying the flood gate so that it can automatically "open" (via hinges at the top of the gate) and drain the area behind the levee in situations where the water level in the Tweed River is lower than the water level behind the levee. The location of the flood gates that have been identified for modification are shown in **Figure H6** in **Appendix H**.

Hydraulic Benefits

The levee gate modifications were included in a modified TUFLOW model and the modified TUFLOW model was used to simulate the 20%, 5%, 1% and 0.2% AEP events. The gates were represented as uni-lateral box culverts that would allow flow in 1-direction only once the water level at the upstream side of the culvert (i.e., behind the levee) exceeded the water level on the downstream side of the culvert (i.e., within the Tweed River).

Flood level difference mapping was prepared for the 20% AEP and 1% AEP. However, this determined that the levee gate modifications would not change peak flood levels at any location. This is associated with:

- During the 20% AEP, 5% AEP and 1% AEP floods, water levels are not sufficiently elevated behind the levee to reach the gates.
- During the 0.2% AEP event, the water levels are still sufficiently elevated within the Tweed River to prevent the gates operating at the peak of the flood;

Time of inundation difference mapping was prepared and stage hydrographs were also extracted for the 0.2% AEP event to determine if the levee gate modifications would have any impact on flood levels before/after the peak of the flood or would assist in draining the area behind the Commercial Road levee more rapidly.

Reductions in inundation times are predicted during the 0.2% AEP, as shown in **Plate 39**. The reductions are generally only predicted to benefit the perimeter of the floodplain that are located at an elevation above the bottom of the gate. However, a significant proportion of the Murwillumbah commercial area / CBD would also benefit. The inundation time reductions are predicted to be about 3 hours across these areas.

The stage hydrographs (refer **Appendix K**) indicate that the levee gates afford negligible hydraulic benefits behind the levee during the rising limb of the hydrograph. However, once water levels in the Tweed River drop, the levee gates become active and allow water levels behind the levee to drop more readily. However, the stage hydrographs show that once the water level behind the levee drops below 5 mAHD (i.e., roughly the elevation of the bottom of the flood gates), negligible additional benefits are afforded. This is associated with the water levels behind the levee dropping below the bottom of the gates and being reliant on the existing stormwater and pump system behind the levee to drain the area.

Overall, the levee gates modifications are predicted to afford minimal hydraulic impacts. However, some reductions in inundation times are anticipated during larger floods (e.g., 0.2% AEP flood and larger).

Economic Benefits

It is expected that the levee gates modifications would cost approximately $60,000 to implement. A detailed breakdown of the cost estimate is provided in **Appendix I**.

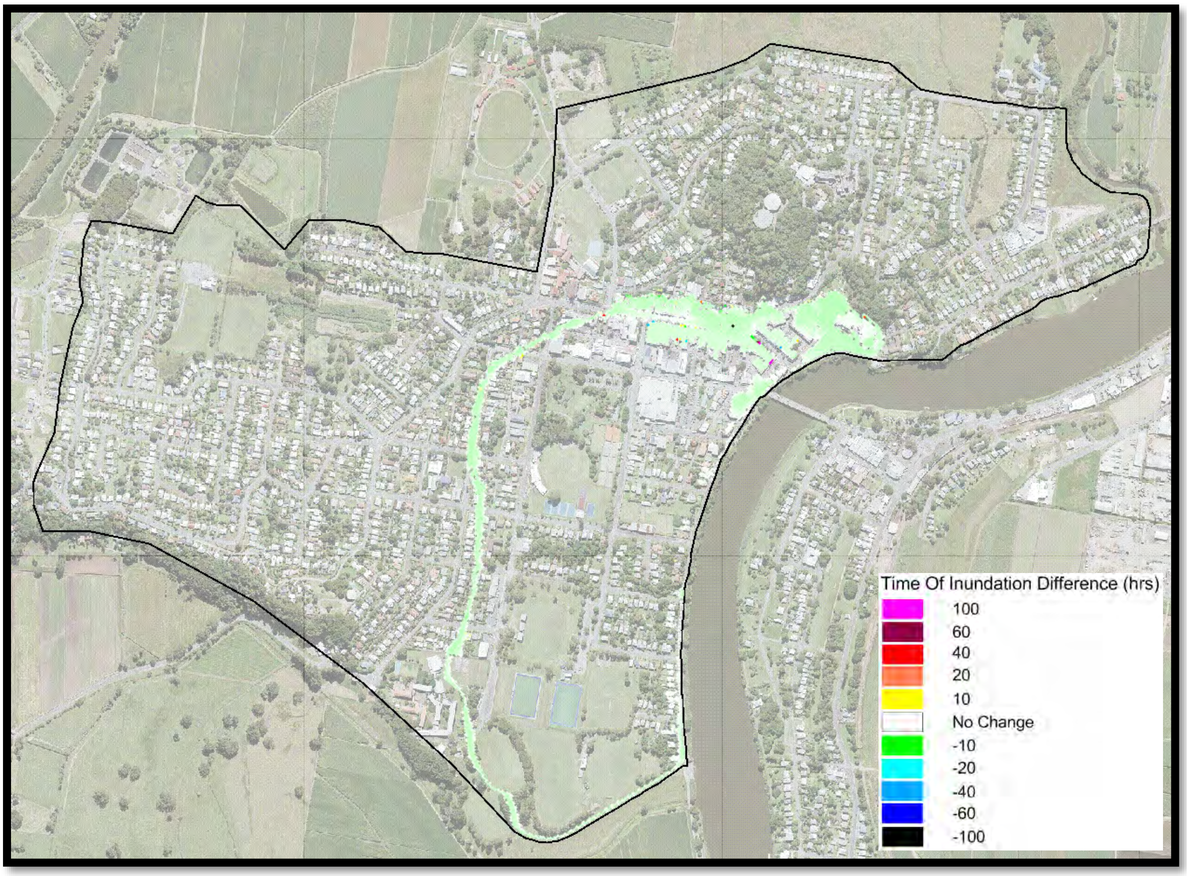


Plate 39 Peak 0.2% AEP Flood Time of Inundation Difference Mapping for Levee Flood Gate Re-design

A revised damages assessment was completed based on the results of the revised simulations. However, this determined that there would be no reduction in flood damages. Accordingly, the BCR for this option would be zero.

Community Acceptance

The levee gate modifications were generally well supported by the community with the majority of the community "strongly supporting" the option (refer **Plate 40**).

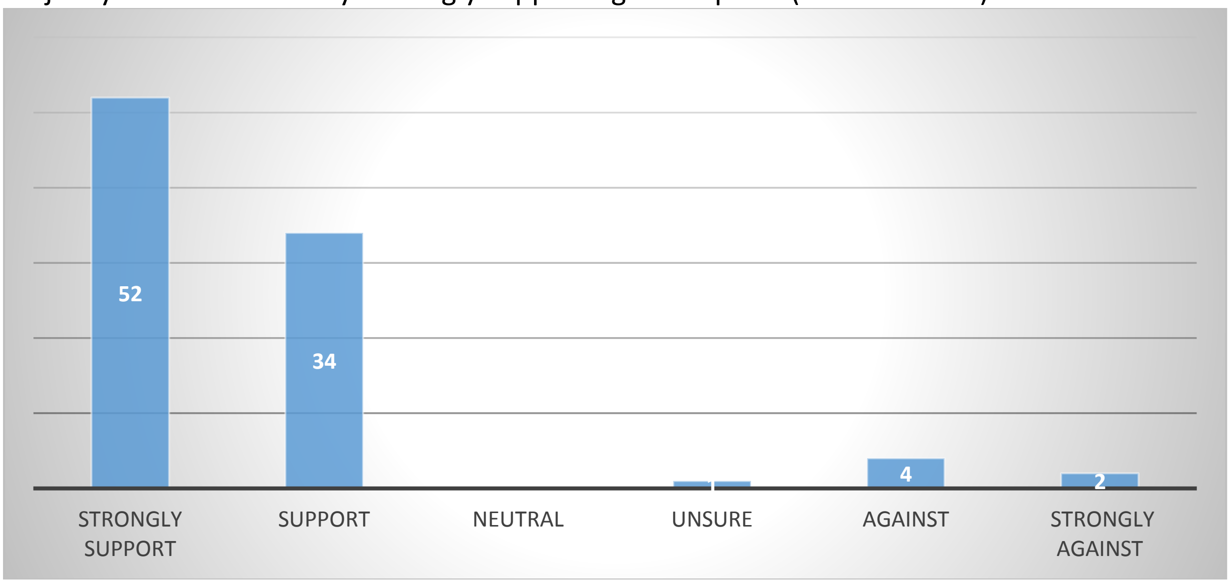


Plate 40 Community response to re-design of Commercial Road levee gates

Emergency Response Benefits

The levee gate modifications would not reduce roadway inundation times in the lead up the peak of the flood or provide any additional flood warning time. Therefore, the emergency response benefits of this option would be minimal.

Option: Option F – Commercial Road Levee Gate Modifications
Recommendation: Not recommended for implementation

6.5 Property Modification Options

6.5.1 Option G - Planning Recommendations

Tweed Shite Council identified several areas within the study area where development pressure may arise in the near future (refer hatched areas in **Plate 41**). Therefore, a review of these areas was completed to determine if:

- Development across these areas may increase the existing flood risk in other areas;
- Development of these areas is considered appropriate based upon consideration of the existing and potential future flood risk; and,

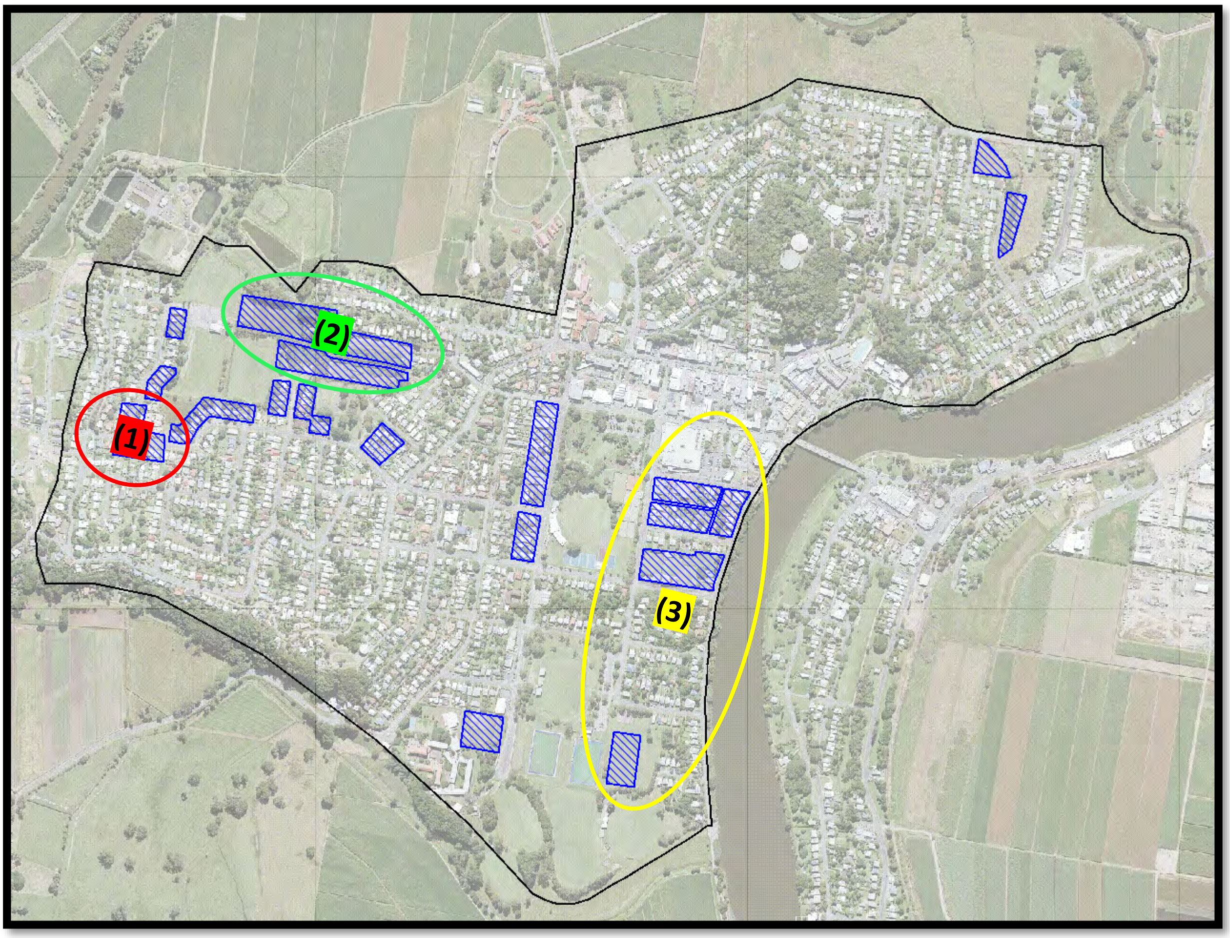


Plate 41 Areas of potential future development/re-development

In addition, Council requested that more definitive design flood levels be provided for areas contained behind the Commercial Road levee to assist in defining minimum floor levels for future development.

Hydraulic Impacts

Development of the hatched areas in **Plate 41** would typically require earthworks to elevate habitable areas to at least the flood planning area. This would typically remove some flood storage volume. Furthermore, any buildings in these areas have the potential to divert any flows across neighbouring properties. Therefore, to assess the potential for future development across these areas to impact on existing flood behaviour, the full extent of the hatched areas in **Plate 41** were elevated above the peak level of the 1% AEP flood.

Additional 20%, 5%, 1% and 0.2% AEP flood simulations were completed with each of the potential future development areas filled. Difference mapping was prepared to quantify the impact that the cumulative filling would have on existing flood levels. The difference mapping is provided in **Plates 42, 43, 44** and **45**.

Plate 42 indicates that the most significant impact during the 20% AEP event is predicted to occur behind the Dorothy Street levee. Flood level increases of 0.17 metres are predicted immediately behind the levee with localised increased of up to 0.7 metres predicted near the intersection of William and Dorothy Streets. Flood level increases behind the Commercial Road and Dorothy Street levees are less significant with most flood level increases predicted to be less than 0.1 metres.

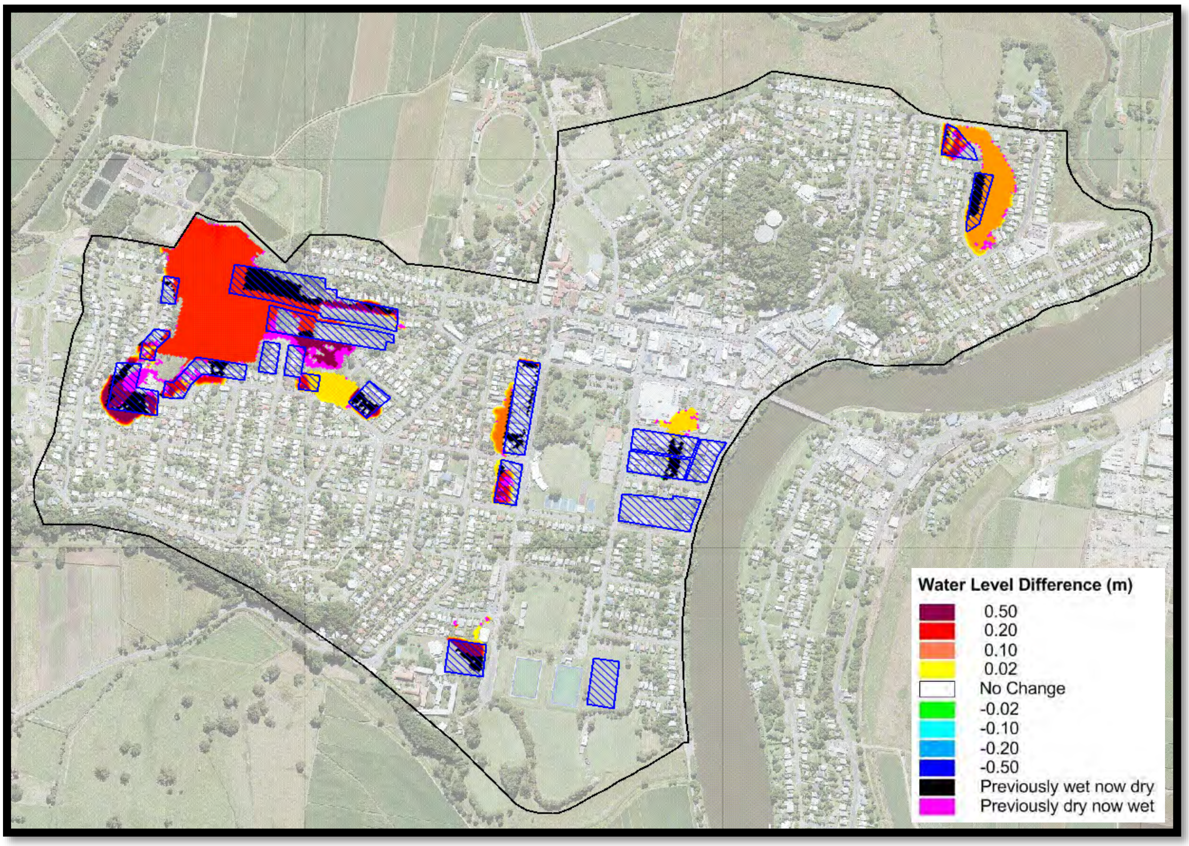


Plate 42 Peak 20% AEP Flood Level Difference Mapping for the Cumulative Impact scenario

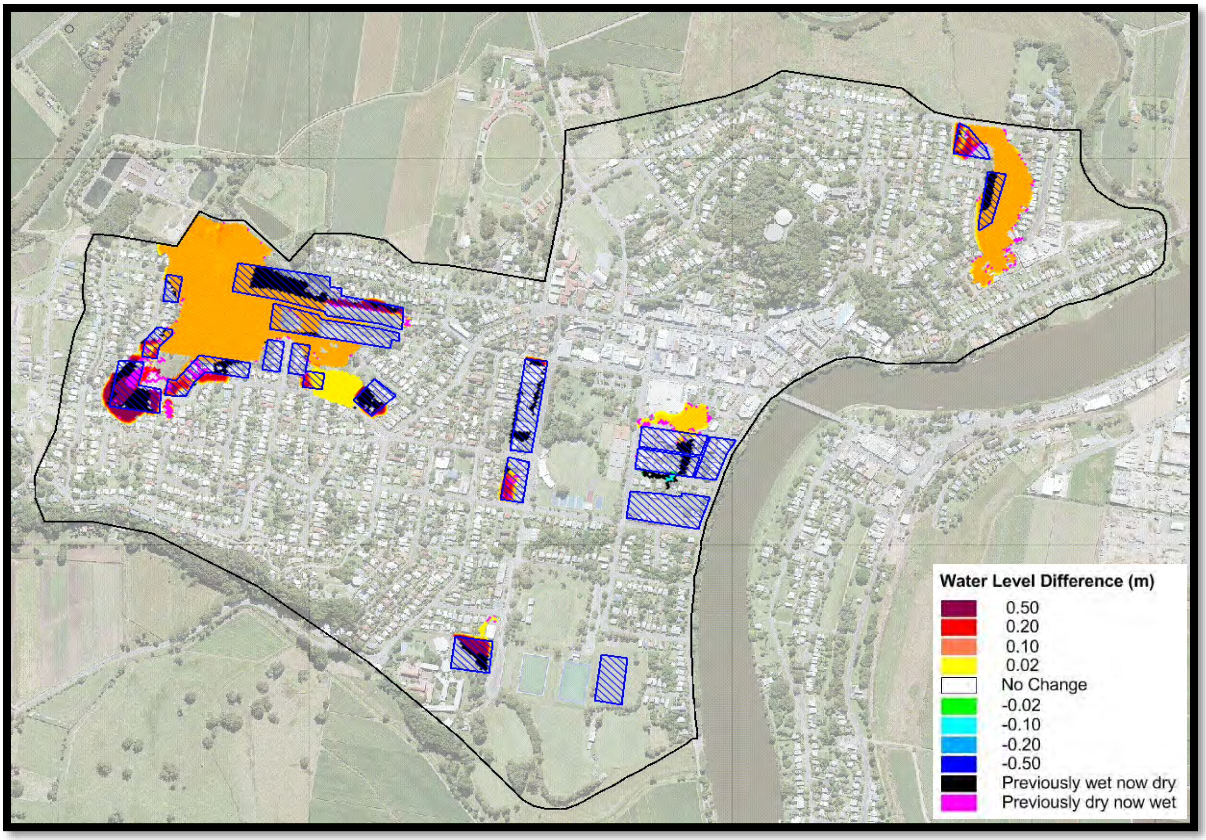


Plate 43 Peak 5% AEP Flood Level Difference Mapping for the Cumulative Impact scenario

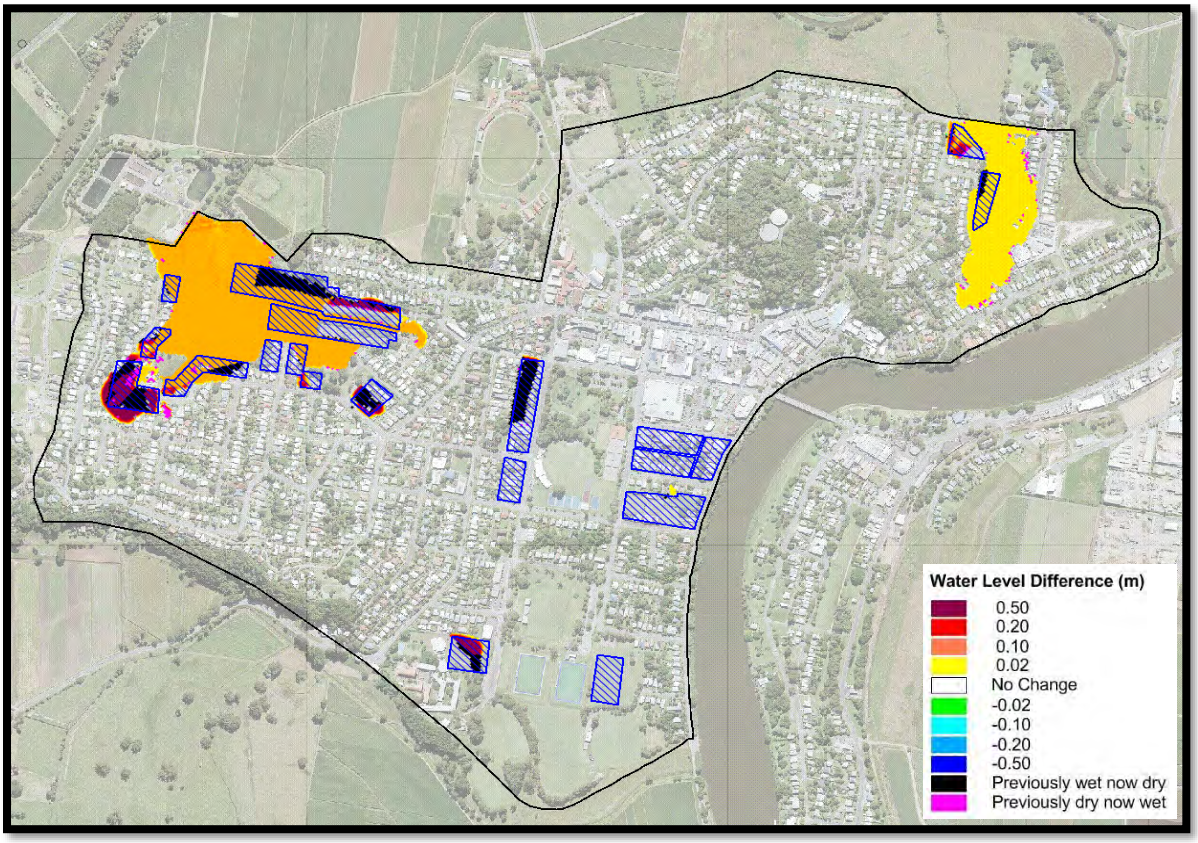


Plate 44 Peak 1% AEP Flood Level Difference Mapping for the Cumulative Impact scenario

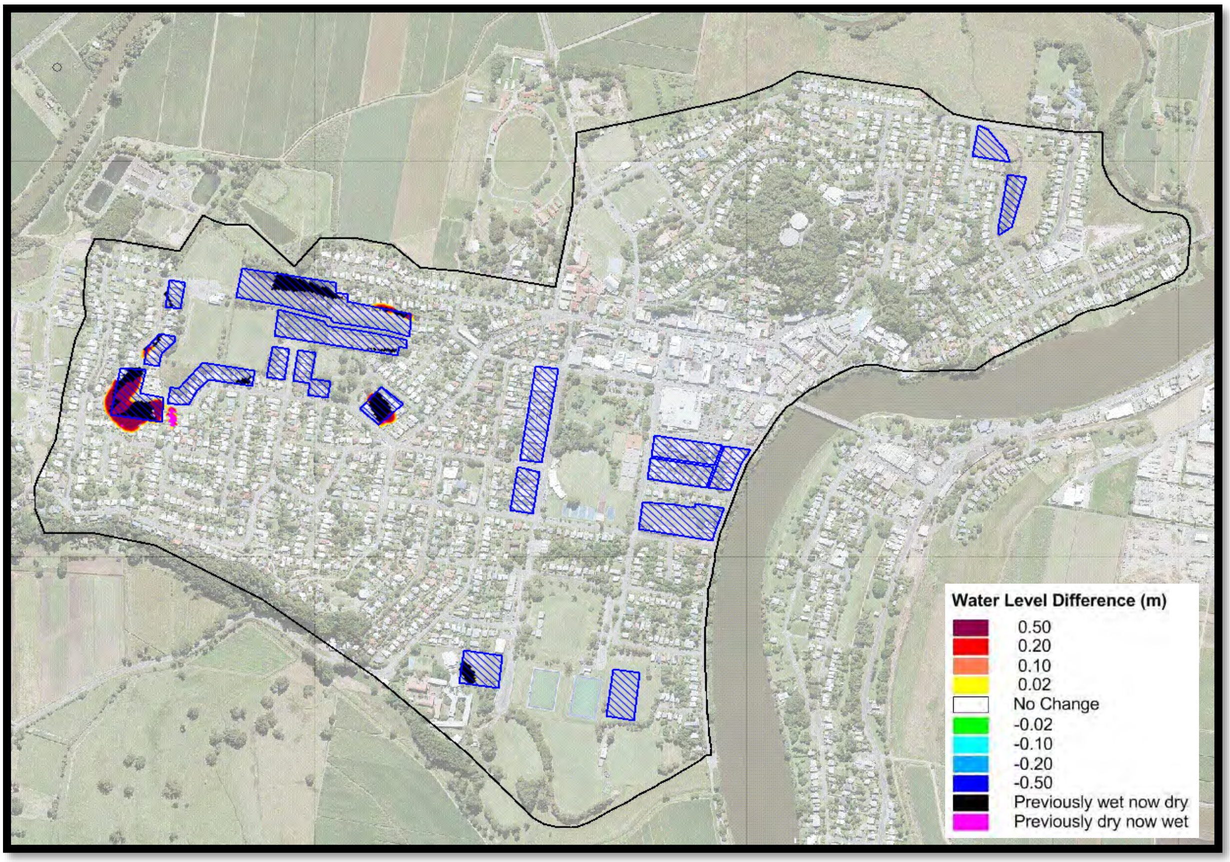


Plate 45 Peak 0.2% AEP Flood Level Difference Mapping for the Cumulative Impact scenario

Plates 43, 44 and **45** show that the flood level impacts typical reduce as the size of the flood increases. More specifically, flood level increases are typically less than 0.1 metres during the 5% AEP and 1% AEP floods and are less than 0.02 metres during the 0.2% AEP flood. The reducing sensitivity to floodplain filling as the severity of the flood increases is associated with the proportion of flood storage volume being displaced during larger events being lower.

The areas that appear to be the most sensitive to filling is near the intersection of Dorothy Street and William Street (refer area (1) in **Plate 41**). The inclusion of additional fill at this location removes a notable storage area within the roadways. This displaces a significant volume of water and forces it into neighbouring properties. Accordingly, if development modifications were to occur across this area, it will be necessary to carefully consider the potential locations of filling to help ensure that flood storage volume is not lost.

Area (2) in **Plate 41** also has the potential to displace a significant volume of water (this area is the primary reason for the flood level differences immediately upstream of the Dorothy Street levee. Therefore, filling to the full extents shown in **Plate 41** may not be possible.

Overall, the results of the cumulative development hydraulic assessment show that some areas contained behind each levee can be sensitive to floodplain filling, particularly during smaller floods. Although the flood level increases behind the Commercial Road and East Murwillumbah levees are not particularly large, the flood level increases behind the Dorothy Street levee are more significant. Therefore, care will need to be exercised across this area as future development occurs to ensure flood impacts are minimised.

Flood Risk Assessment

An assessment was undertaken of the potential future development/re-development of the areas shown in **Plate 41** relative to the results of the design flood simulations to determine if development/re-development may expose future occupants of these areas to an unacceptable flood risk or intensification of population in this area may place increased reliance on the SES.

In general, any future development that is completed in accordance with Council's minimum floor level requirements will help to minimise the potential for property damage during floods up to and including the 1% AEP event.

Each of the future development areas typically backs on to land that is elevated above the 1% AEP flood or has access to roadways that grade up and out of the floodplain. Therefore, any future occupants of these sites can likely move from these areas to the evacuation centre without an increased reliance on the SES.

The most notable exception to this rule are the areas located to the east of Knox Park (area (3) in **Plate 41**). The outcomes of the existing flood assessment show that these areas can become isolated prior to levee overtopping. Accordingly, any increase in population density in these areas may increase the reliance on the SES should evacuation not occur sufficiently early. For this reason, intensification of residential development in these areas is not considered to be a viable option. However, re-development of these areas for commercial purposes or open space/recreations may provide a net reduction on reliance on the SES as it would remove some existing residential properties and only a transient population would be present (and typically only in daylight hours where evacuation is more readily achievable).

It is also noted that the area bound by Nullum Lane, Nullum Street, Wollumbin Street and Prince Street is also surrounded by floodwater at the peak of the 1% AEP flood. Therefore, re-development for residential purposes is also difficult to support from an increase in risk perspective. However, re-development for commercial purposes may be viable.

Design Flood Levels

Tweed Shire Council requested that peak design flood levels be extracted from the results of the revised modelling to assist in ensuring floor levels for future development are elevated to reduce the risk of above floor flooding (i.e., reduce the potential for an increase in flood damages).

Accordingly, the peak design flood level results were extracted for the area behind the Commercial Road levee and are presented below.

- 20% AEP = 3.04 mAHD
- 5% AEP = 3.21 mAHD
- 1%AEP = 3.85 mAHD;
- 0.2%AEP = 7.40 mAHD

It is suggested that the floor levels of future development be elevated to at least the level of the 1% AEP flood (3.85 mAHD). The ground surface elevation (refer **Figure 3**) across most of the lower lying areas behind the Commercial Road levee are located above 3 mAHD (excluding

Knox Park). Therefore, some of the lower lying areas would require the floor level to be elevated more than 0.5 metres above the adjoining ground surface. However, most properties east of Brisbane Street and west of Nullum Lane are typically located above 3.5 mAHD and would require minimal additional filling/elevating to meet this minimum floor level requirement.

Option: Option G – Planning Recommendation
Recommendation: Areas earmarked for future development are typically compatible with the flood risk and should not significantly impact on existing flood behaviour. However, some areas are more sensitive from a flood risk and flood impact perspective and care will need to be exercised if future development or re-development occurs in these areas. Furthermore, it is recommended that floor levels for future development are elevated to at least the level of the 1% AEP flood.

6.5.2 Option H - Temporary Flood Barriers for Commercial Properties

Description of Option

As outlined in Section 5.3.3 and 5.3.4, much of the above floor flooding and flood damage cost across Murwillumbah is incurred across commercial properties. In general, the options evaluated in Section 6.4 provided limited flood level reductions across the commercial areas of Murwillumbah (most notable Wharf Street / Muwrillumbah Street).

Therefore, the potential benefits associated with providing temporary flood barriers were investigated as a means of reducing flood damages and disruption to commercial businesses in Murwillumbah.

Examples of temporary flood barriers are provided in **Plate 47**. As shown in **Plate 47**, the barrier arrangement would include a permanent bracket attached to the frontage 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.

Economic Assessment

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 above floor inundation during events up to and including the 1% AEP were initially identified as candidates for temporary flood barriers. The location of each of these properties is shown in **Plate 47**.

The properties in **Plate 47** were further subdivided according to their damage potential. Green points indicate above floor flooding is predicted during the 1% AEP but the specific type of commercial property would mean low flood damages costs are likely (e.g., sheds adjoining sports fields). Red points indicate above floor flooding in a 1% AEP flood and a higher flood damage potential. Therefore, priority should be given to the red points in preference to green points if the greatest value for money is desired.

Plate 46 Examples of temporary flood barriers (provided courtesy of Flood Control International)

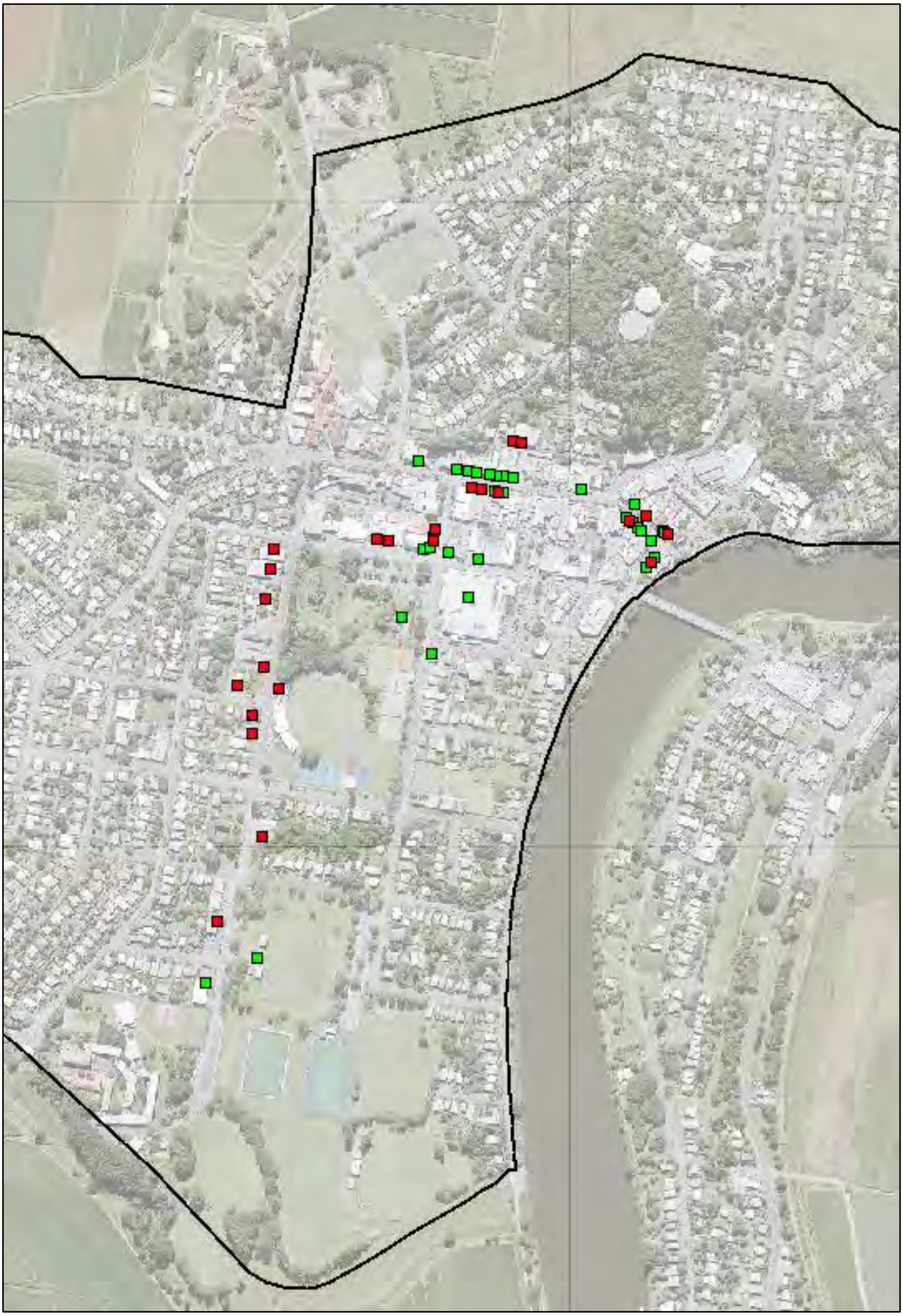


Plate 47 Location of commercial properties that could benefit from Flood Barriers (green indicates those with low flood damage potential and red indicates higher flood damage potential)

Most of the properties identified in **Plate 47** are subject to above floor flooding depths of less than 0.9 metres. Therefore, it was assumed that 0.9 metres high barriers would be provided. A temporary flood barrier that is 0.9 metres high along a 5m property frontage costs in the order of $21,000. Therefore, to protect all of the 56 properties identified in **Plate 47** would cost $1,176,000. To protect just the "high priority" properties (i.e., 23 red properties in **Plate 47**), the total cost would be about $483,000.

A revised flood damage assessment was completed by updating the commercial flood damage curves. This involved removing all flood damage costs for over floor flooding depths of less than 0.9 metres. Once inundation depths exceeded 0.9m 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 the flood barriers would reduce average annual damages by $94,000 per annum. This translate to a total flood damage reduction of $1.3 million over 50 years and a benefit cost ratio of 1.1. Therefore, the damage reductions associated with the temporary flood barriers appear to outweigh the costs.

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.

It should also be noted that the barriers will likely only afford benefits during events up to and including the 1% AEP event. During particularly large floods (e.g., 0.2% AEP flood), over 3 metres depth of water is predicted behind the Commercial Road levee and temporary flood barriers of this height are not available.

Community Acceptance

The temporary flood barriers were generally supported by the community with the majority of the community "supporting" the option (refer **Plate 48**).

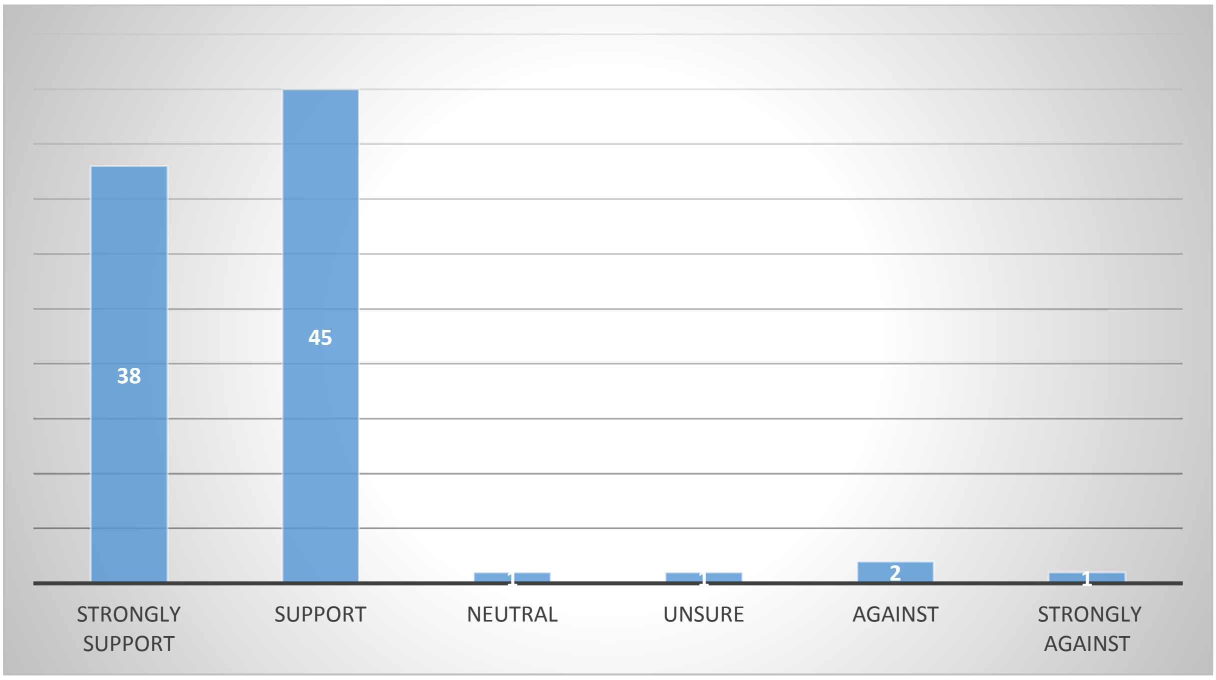


Plate 48 Community response to temporary flood barriers

Emergency Response Benefits

In particularly severe floods, the temporary barriers may provide additional time for shop owners to relocate stock to 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).

Option: Option H – Temporary Flood Barriers
Recommendation: Recommended for implementation

6.6 Response Modifications

It should be acknowledged that none of the flood management options considered as part of this study will afford significant benefits during particularly large floods, such as the PMF. Therefore, a continuing flood risk will remain. The continuing flood risk is typically best managed through appropriate response modification measures. Response modification measures aim to change the way in which emergency services as well as the general public responds before, during and after a flood.

6.6.1 Option I - Local Flood Plan / Flood Intelligence Updates

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 ex-tropical cyclone Debbie 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;
- Emergency response precinct classifications; and,
- Predicted road inundation locations and details (including road overtopping times and durations of inundation).

Option: Option I – Local Flood Plan updates
Recommendation: Update Local Flood Plan to incorporate new flood intelligence

6.6.2 Option J – Flood Warning System

Background

The purpose of a flood warning system is to provide advice on impending flooding so people can take action to minimise its negative impacts. An effective flood warning system requires integration of a number of components (Australian Government, 2009):

- monitoring of rainfall and river flows that may lead to flooding;

- prediction of flood severity and the time of onset of particular levels of flooding;
- interpretation of the prediction to determine the likely flood impacts on the community;
- construction of warning messages describing what is happening and will happen, the expected impact and what actions should be taken;
- dissemination of warning messages;
- response to the warnings by the agencies involved and community members; and,
- review of the warning system after flood events.

Where effective flood warnings are provided, risk to life and property can be significantly reduced. Studies have shown that flood warning systems generally have high benefit-cost ratios if sufficient warning time is provided and if the population at risk is aware of the threat and prepared to respond appropriately.

The Bureau of Meteorology (BoM) issues a number of products that provide warning of floods, including Severe Weather Warnings for torrential rain and/or flash flooding, and Flood Watches that typically provide 24 to 48 hours' notice that flooding is possible based upon current catchment conditions and forecast rainfall.

The BoM also maintains a hydrologic model which uses recorded and forecast rainfall to predict the magnitude of flooding across the catchment. The BoM issues flood height estimates based on the results of the hydrologic modelling at several stream gauges including the Tweed River at Murwillumbah.

In addition to the BoM flood level forecasts, the SES monitors a number of additional stream gauges that aim to provide an improved understanding of the severity of an impending flood as it occurs.

Therefore, there is an existing flood warning system in place for the Tweed River catchment. However, as part of the community responses, many community members felt that insufficient flood warning information was made available in a timely manner so that appropriate preparation for the flood by the wider community could be undertaken.

In light of this feedback, opportunities to improve the flood warning system was were investigated.

Flood Warning System Requirements

The Bureau of Meteorology's Flash Flood Advisory Resource (FLARE) was used as a resource for identifying potential improvements to the flood warning system. FLARE includes a method of assessing risk. A 1% AEP flood ('unlikely' likelihood) would cause damage to multiple residential and commercial properties ('high' consequence), which translates to a 'medium' risk. FLARE suggests that a medium risk requires an 'advanced' flood warning system. Elements of such a system are depicted in **Table 18**. Comments are also provided regarding whether the current flood warning system meets each of the recommended requirements.

Table 18 Components of an advanced flood warning system

Total Flood Warning System element	Advanced Flash Flood Warning System components	Comments
Monitoring and Prediction	• Severe weather warnings • Severe Thunderstorm Warnings • Flood Watches • Access to real-time information from weather radar. • Real-time information from rain gauges installed in the flash flood area. • Rainfall triggers (depth/duration e.g. 30mm in an hour) set to warn of onset of flooding. • Real-time information from river gauges installed in the flood locality. • READY (monitor), SET (prepare), GO (act) based on Bureau warnings, observed rainfall triggers and observed river level triggers respectively.	• Available • Available • Available • Available • Available • Available (rainfall in excess of 120mm per day is currently used to trigger a flood watch) • Available • Available
Interpretation	• Some flood studies and flood modelling/mapping may have been carried out. • Interpretation from historical data and SES flood intelligence to link triggers to impact on the ground.	• Available. But detailed outputs from current study can be used to provide more detailed flood information • Available
Message Construction	• Standard Bureau messages for weather warnings and flood watches. • Predefined flash flood warning messages for READY, SET, GO phases.	• Available • Available
Communication	• Bureau warnings and information available on the web, and broadcast by the media. • Direct and automatic dissemination of warnings to the affected community e.g. via SMS	• Available • Not currently available

Total Flood Warning System element	Advanced Flash Flood Warning System components	Comments
Response	Generally proactive community and SES response underpinned by local recurrent public flood awareness and education program.	Could be improved through community education program
	Good community awareness of flooding and personal actions required; some community members have personal flood plans prepared.	Could be improved through community education program
	A Municipal Flood Emergency Plan (MFEP) or response plan exists but has gaps or requires updating.	Available although could be updated to take advantage of learnings from ex-tropical cyclone Debbie as well as outputs from the current study
Review	Review performance of the system (including each individual element) after each significant flood event.	Included in Local Flood Plan.
	Regular and scheduled reviews of the readiness and maintenance of system components such as gauges, communications, public education and planning.	Advice from SES indicates some gauges are not operational. Therefore, potential to improve.

Source: FLARE (Bureau of Meteorology)

The information contained in **Table 18** shows that most of the existing flood warning system satisfies most of the desired flood warning system requirements. However, improvements across three main areas may assist in improving the existing flood warning system. These are discussed in more detail below.

Communication

Communication of flood warnings is vital. At the current time, people's ability to look up a web portal (such as the BoM website) or to directly receive landline phone warnings could be compromised by electricity outages (not uncommon during severe weather).

However, Murwillumbah and surrounds does have good mobile phone coverage which are less likely to be directly impacted by power outages (assuming sufficient battery power and/or access to USB "power banks"). However, the current flood warning system does not include a facility to provide flood warning to the broader community via SMS. As most households and businesses own at least one mobile phone, it is suggested that taking advantage of SMS messaging would provide an avenue for improved dissemination of flood information.

Some community members also suggested installing video cameras at known flooding trouble spots/levee overtopping locations and streaming videos from these cameras online. This would allow the broader community to view flooding information in real time without the need to leave their home/business. Having a real-time video showing significant flooding/levee overtopping may serve as a bigger motivation for evacuation than an SMS message. Although this is not considered to be an essential part of any upgraded flood warning system (and is subject to potential limitations associated with power outages), it is a component that Council may consider as a means of communicating the flood risk via a range of different media.

It should be noted that any sort of SMS messaging system will need to be supplemented by appropriate education materials to ensure the community knows how to interpret the information contained in the message and what actions to take. Community education is discussed in more details below. It is also recommended that community education programs recommend households and businesses purchase power banks to ensure phones can be kept charged during floods when long power outages may occur.

Other online media outlets such as Council's Facebook and Twitter pages could also be utilised as an official part of the communication strategy for the flood warning system. This will require potential coordination between SES, Council engineers and Council's communication teams.

Response

As discussed above, the effectiveness of a flood warning system is not only dependent on the distribution of flood information but also ensuring the community knows how to respond to that flooding information. The results of the community questionnaire showed that around 20% of the respondents did not know if their property was at risk of flooding and over half would not evacuate during future floods. Therefore, it is considered that there are opportunities to improve the community response. This could be potentially achieved via a community education program, which is discussed in more detail in Section 6.3.3.

Review

It is important to review the flood warning system following each flood to determine its effectiveness and look at opportunities to improve the system. It is not clear whether reviews of the flood warning system are routinely carried out after an event and/or for system maintenance. However, discussions with SES staff indicate that some gauges are currently not operational. Therefore, it appears that further work could be completed to ensure the system is continually reviewed and maintained.

Community Acceptance

An upgraded flood warning system was strongly supported by the community (refer **Plate 50**). In fact, this option was the most supported of all the options under consideration with no respondents against the option. Accordingly, it strongly indicates the desire for a reliable flood warning system to be provided to assist with preparation and response during future floods for the wider community.

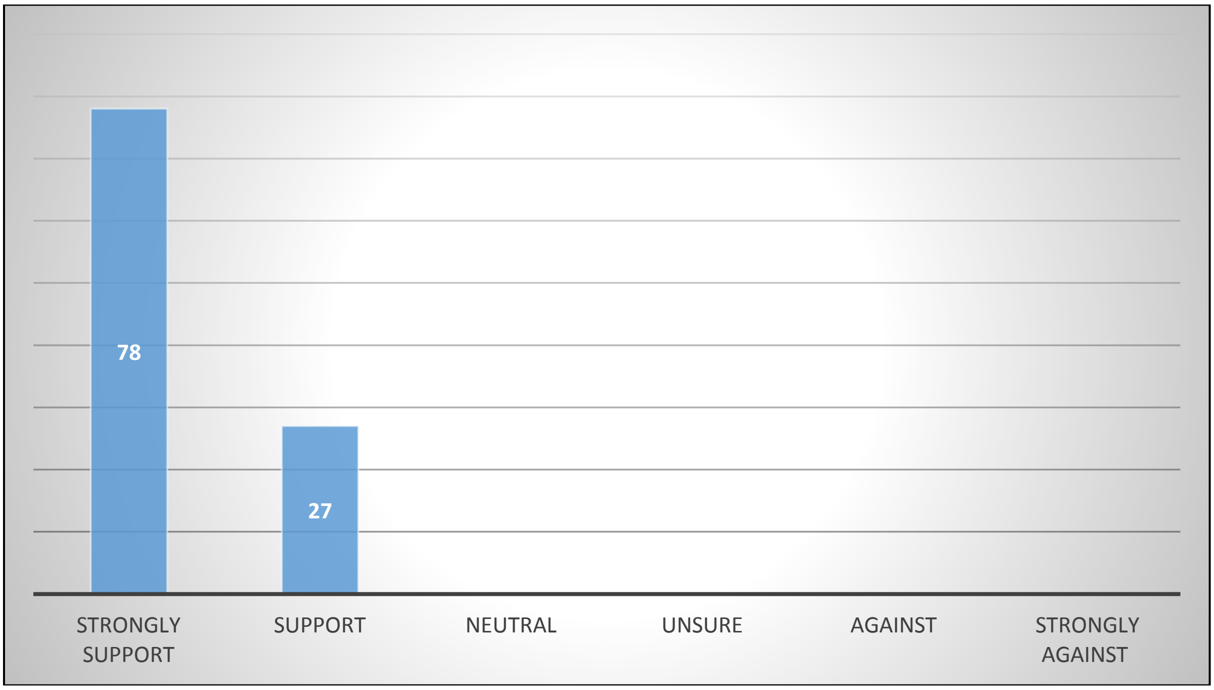


Plate 49 Community response to flood warning system

<u>**Option**</u>: Option J – Flood Warning System
<u>**Recommendations**</u>:
(1) Develop SMS Flood Messaging Service (potentially automated via linkages to river gauges and established trigger levels). Also take advantage of social media outlets
(2) Develop community education program (discussed below)
(3) Provide additional resources for maintenance of flood warning system

6.6.3 Option K - Community Education

As outlined in the previous section, the effectiveness of a flood warning system is highly dependent on having a well-educated community that knows how to interpret flood information and act accordingly. The outcomes of the community questionnaire indicate that there is good basic understanding of the flood risk at an individual property level. However, there are still some community members that do not know if their property is at risk of flooding and a significant proportion of the community that would not evacuate during future floods. Therefore, it is considered important for additional community education activities to be undertaken that would target improving the community's understanding of their potential flood risk and the appropriate actions to take during a future flood.

It is difficult to accurately assess the monetary benefits of a community flood education program but the consensus is that the benefits far outweigh the costs. Nevertheless, those responsible for preparation and dissemination of the education materials must appreciate that ongoing funding/resources are required to sustain gains that have been made.

A number of options are available to educate the broader community. Regardless of which option is selected, it is important to understand that simply disseminating non-targeted information does not necessarily trigger changed attitudes and behaviours. More effective education outcomes will be realised by:

- Utilising a range of different media outlets including pamphlets, DVDs, social media, "meet the street" events and flood commemorations
- Are participatory, where possible
- Are ongoing rather than one-offs

The following sections discuss some strategies that could be employed as part of a flood education program.

Flood Markers

Flood markers, showing the peak level that past floods have reached, are generally regarded as an effective method of raising flood awareness in the community. One of the main benefits associated with utilising flood markers is that the flood levels from large floods are typically well established/defined and cannot be disputed like "hypothetical design" floods may be.

Flood height markers from significant floods such as 1954, 1974 and even 2017 could be installed in the area behind the levees to provide a continuous reminder of how high flood waters have reached during past floods. Some examples of flood markers are provided in **Plate 50**.

The effectiveness of a flood marker is highly dependent of the location. The markers should be located in a highly trafficked area to maximise exposure. Therefore, areas in and around the commercial area of Murwillumbah would likely be preferable. It is suggested that Wharf Street (near the intersection with Commercial Road) would be a suitable location. Due to the space constraints within the commercial area, it is likely that a "totem pole" style may be the most appropriate style of marker.

Woronora flood sign | Fairfield flood icon | Kempsey flood totem pole

Plate 50 Examples of flood markers (Bewsher Consulting, 2012)

Recommendation: Install "totem pole" flood marker near the intersection of Wharf Street and Commercial Road

Educational Messages

From the community questionnaire responses as well as experiences during ex-tropical cyclone Debbie, a number of key messages emerge for people in the study area:

- 'Never drive, ride, walk or play in floodwaters'.
  The need to continue broadcasting this message is suggested by the knowledge that motorists in NSW continue to lose their lives when attempting to cross floodwaters, and by the number of roads in the study area that are frequently flooded. Messages could also provide technical information to dissuade drivers from crossing flooded roads, such as the depths at which cars float. Messages could also target the motivations for crossing floodwater, pointing out that it's better to arrive home late than not at all.
- 'One day a bigger, faster flood will happen than what anyone has ever seen. Council has modelled what these floods might be like. Learn whether your house/business could be flooded in an extreme flood. Identify whether it's safe for you to stay or whether you need to evacuate before flooding. Plan ahead to keep your family/staff safe'.
  A message such as this is important because of the high proportion of respondents to the questionnaire who indicated they would not evacuate during a future flood and the need to remind the community that the levee system will be overtopped at some point in the future.

It is considered that periodic dissemination of messages such as this could be completed in Tweed Link newsletter and could be reinforced via social media, particularly if flood watches/wanrings are issued. The "sunny day" messages could be distributed on the anniversary of significant past floods to further reinforce the impact of these past floods on Murwillumbah.

It is understood that the Tweed Valley is serviced by a community FloodSafe Engagement program via the SES. Therefore, these educational messages could also be issued under this program. It will be important for the SES and Council to communicate and coordinate their education strategy/messages to ensure consistency in the messages being distributed to the community.

Recommendations:
- Council and SES to develop education messages/strategy for "sunny day" conditions as well as education messages immediately prior to a flood
- Council to include sunny day flood education messages in Tweed Link newsletter. Prepare a strategy
- Council to strategy to distribute education messages via social media when flood watched/warnings are issued

Property Level Flood Information

A starting point for improving people's readiness for floods is to help them better understand how they could be directly affected by floods. Knowing how their house or business could be directly affected by floods is more likely to cut through the scepticism that can grow when communities are not flooded for some years, than more generic advice.

Advancements in flood modelling software and associated spatial datasets has significantly enhanced the quantity and quality of information from flood studies and floodplain risk management studies available at the property level. Council already makes a range of flood information available on their website, including various flood maps. But additional resources would be beneficial to explain what this information means and how it could be used to assist in the preparation of property level flood response plans.

Several community members noted that there is some uncertainty within the community about where to source flood information (including flood warnings). Therefore, it is considered desirable to avoid distributing flood information across multiple sites to help ensure this uncertainty is avoided (i.e., hold all flood information on a single website). Therefore, there may be benefits in developing a dedicated flood portal (or expanding the capacity of Council's existing website) to serve as a central repository for flood information.

The high level of detail available from the Emergency Response Planning Classification tool also makes it possible to prepare customised flood information flyers, fridge magnets etc for individual properties. These flyers/magnets can be printed by specialist printers using mail merge techniques to provide property level information for all potentially flood liable properties. Alternatively, the flyers/magnets can be generated via a website and individual property owners can print their own. Information that could be potentially included on a customised flyer/magnet may include:

- A gauge diagram for the Tweed River at Murwillumbah showing the peaks of past floods and information on the gauge level typically coinciding with levee overtopping or when evacuation routes may close.
- The closest evacuation centre, approximate driving distance and even the best route. This could even be presented as a map.
- Identification of any special risk factors such as being in an area that may get surrounded by floodwaters or an area at risk of flash flooding.

Software, such as WaterRIDE™, can also automate the preparation of documentation summarising key flood parameters at the property scale including graphics depicting inundation extents. An example of property level flood information generated by WaterRIDE™ is shown in **Plate 51**.

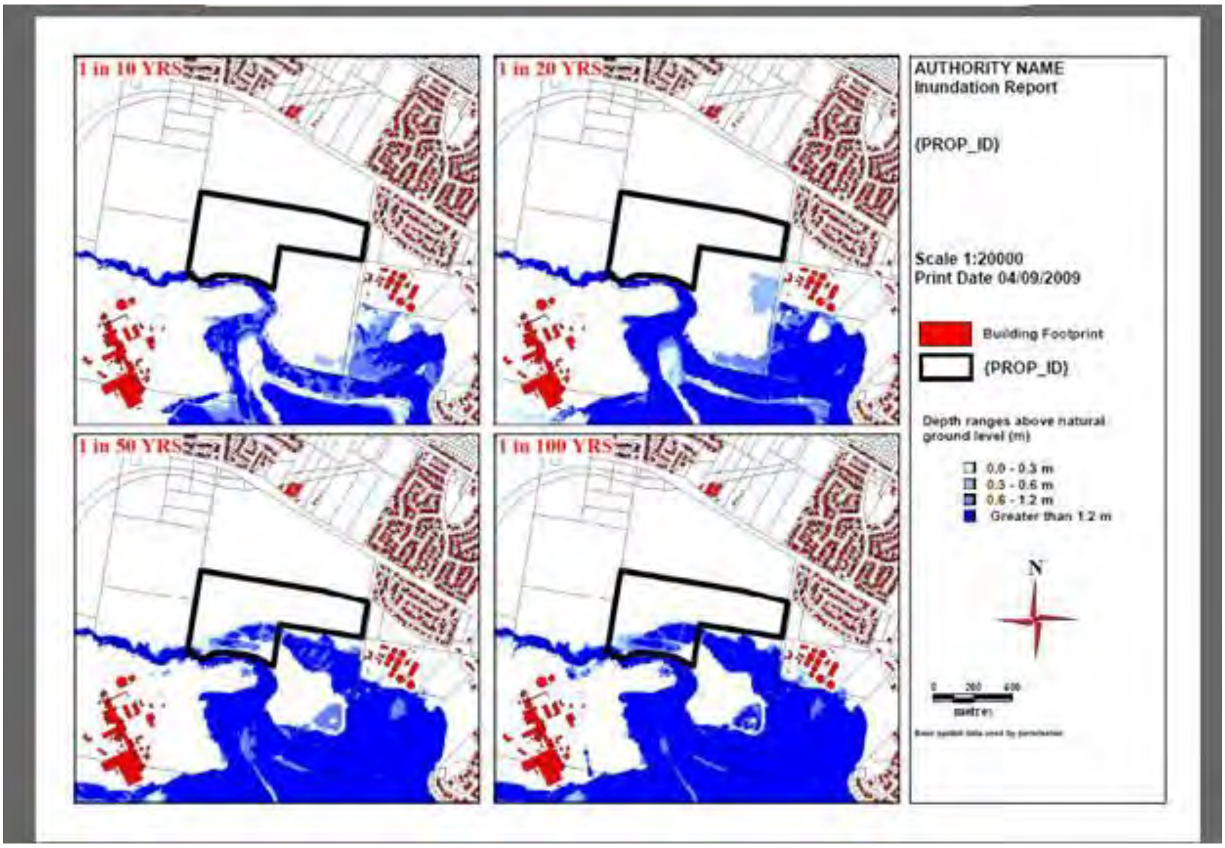


Plate 51 Example of property level flood information provided by waterRIDE (images provided courtesy of Advisian)

Recommendations:

1) Make available additional flood information at a property scale, including flood emergency response classifications, with suitable explanations and guidance as to how this information can be used to inform flood emergency planning

2) Consider undertaking a pilot project involving the distribution of property level flood information to a small section of the study area (e.g., area behind Commercial Road levee)

Flood Information Portal

As discussed, the development of a flood information portal is likely to be an effective means of emergency response planning by facilitating the wide spread distribution of flooding information to emergency services as well as the public. This could be facilitated by expanding Council's existing website or through the development of a separate website dedicated specifically to flooding across the Tweed Shire Council LGA.

A flood information portal would aim to provide the following:

- Information that will allow property owners to understand their existing flood risk which can "feed" into the preparation of a flood plan.
- Real time flood information that can be accessed during floods (e.g., flood warnings, current & projected water levels at gauges).

An advantage of websites is their ability to be a living document incorporating current information sources such as flood mapping, BoM flood warnings, live information on nearby river and rain gauges and the latest advice from relevant organisations such as the SES and RMS. Therefore, assuming the website is maintained, it can serve as a central repository for a range of contemporary flood information.

Some of the potential capabilities of flood portals in order of increasing complexity are:

- 'Pull' style (on demand user requested) distribution of generic and regionalised flood information flyers;
- 'Pull' style re-broadcasting of relevant information such as flood warnings and SES alerts;
- 'Push' (based on prior opt-in or subscription) of information based on email / SMS subscription lists;
- Generation of customised flood information flyers for individual properties;
- Showing 'live' river and rainfall gauge information in the context of past floods and peak rainfall events. This can also include live identification of flooded roads and identification of alternative flood evacuation routes for any point in the catchment; and,
- Integration with rainfall forecasting systems and real-time flood modelling to predict the extents and timing of the current flood and generate required warnings.

Recommendation: Undertake a flood information portal pilot study to develop a basic web site. Functionality could be expanded as funding becomes available

7 CONCLUSION

This report has summarised the outcomes of a levee overtopping and drainage study that was completed for the township of Murwillumbah. The study aimed to quantify the nature and extent of the existing flooding/drainage problem behind the existing levee system and also quantify the potential impacts across the township should the existing levee system be overtopped. The study also investigated options that could be potentially implemented to help reduce the impacts of flooding on the Murwillumbah community.

The study was completed based upon a TUFLOW computer flood model that was originally developed as part of the *'Tweed Valley Flood Study'* (BMT WBM, 2005). However, the model was updated as part of the current study to include a more detailed description of the terrain, the levees as well as the stormwater drainage and pump systems.

The outcomes of the modelling determined that overtopping of the levee system is not anticipated until the 1% AEP event, where the southern section of the Commercial Road levee is predicted to overtop. However, flooding can still occur behind the levees during smaller events as the existing stormwater system struggles to operate due to elevated water levels within the Tweed and Rous Rivers.

All three of the levees protecting the main township of Murwillumbah (i.e., the Commercial Road, East Murwillumbah and Dorothy Street levees) are predicted to be overtopped during a 0.2% AEP event. If overtopping of the levee does occur, it can take multiple days to drain the area behind the levee. Damage calculations indicate that average annual flood damages for Murwillumbah would be in the order of $1.1 million for existing conditions.

Twelve different options were investigated to determine their effectiveness in reducing the existing flood risk behind the levee. The options aimed to address the flood risk during smaller events as well as bigger events that overtop the levee system. Each option was evaluated against a range of criteria including the potential of each option to reduce existing floodwater depths and extents, the financial benefits and costs of each options as well as the potential emergency response benefits.

The following options were ultimately selected for further investigation/perusal to assist in better managing the flood risk behind the Murwillumbah levee system:

- Remediation of Commercial Road Levee, including installation of formalised spillway
- Installation of a new pump system for the Dorothy Street levee
- Temporary flood barriers for commercial properties
- Local Flood Plan / Flood Intelligence Updates
- Flood warning system upgrades
- Community education

The Proudfoots Lane pump system was also determined to provide some significant hydraulic benefits across the Murwillumbah CBD. However, the high cost of this option may make it impractical. Nevertheless, it could also be pursued if funding does become available in the future.

It should be noted that although each of the options investigated will assist in reducing the existing flood risk, no one option will be able to eliminate the flood risk across Murwillumbah completely. Therefore, there will still need to be an ongoing focus on emergency response and community education activities to ensure the residual flood risk is well managed.

8 REFERENCES

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- Keys, C. (2002). *A combat agency and its hazard: a New South Wales State Emergency Service perspective on the management of flooding*, Australian Journal of Emergency Management, 17(2), 14-18, 50-55.

APPENDIX A

PUMP DETAILS

A ORIGINAL ISSUE

COMPUTER DETAILS		
COMPUTER I.D. LEVPUMP	DESIGNED SP	THESE DRAWINGS HAVE BEEN TAKEN TO THE SITE OF THE WORK AND ARE RECOMMENDED
PLOT FILE NAME:	DRAWN GC	DESIGN ENGINEER S Pa[illegible] DATE: 29.1.91
BACKUP TAPE:	CHECKED SP	SHIRE ENGINEER per D McA[illegible] DATE: 29.1.91
DISK LOCATION:	FIELD BK. / LEVEL BK. / DATUM AHD / SCALE 1:25	

TWEED SHIRE COUNCIL

STORM WATER PUMP STATION.
TUMBULGUM RD.MURWILLUMBAH

ISSUE A
SHEET OF SHEETS
DRAWING No. A1-890-71

ATTACHMENT B – PUMP INFORMATION

KILLARA FORGE PTY LTD
ABN 57 059 055 944
Trading as
PATERSON PUMPS
2 Nicholas Drive, MOAMA NSW 2731
P.O. Box 1, MOAMA NSW 2731
Telephone: (03) 5480 9470 BH. Fax: (03) 5480 9471
Email - sales@patersonpumps.com.au
Web Page - www.patersonpumps.com.au

DRAINAGE UNION - LAVENDER CREEK
ANNUAL SUPPLY

Attention: Trevor NEL
Tweed Shire Council
Tumbulgum Road
MURWILLUMBAH N.S.W 2484

Re EC2004-87A " Supply of Flood Pumps Only"

Dear Trevor

Please find attached certified test curves as agreed upon in the above contract and including amendments.
Awaiting you reply to verified receipt.

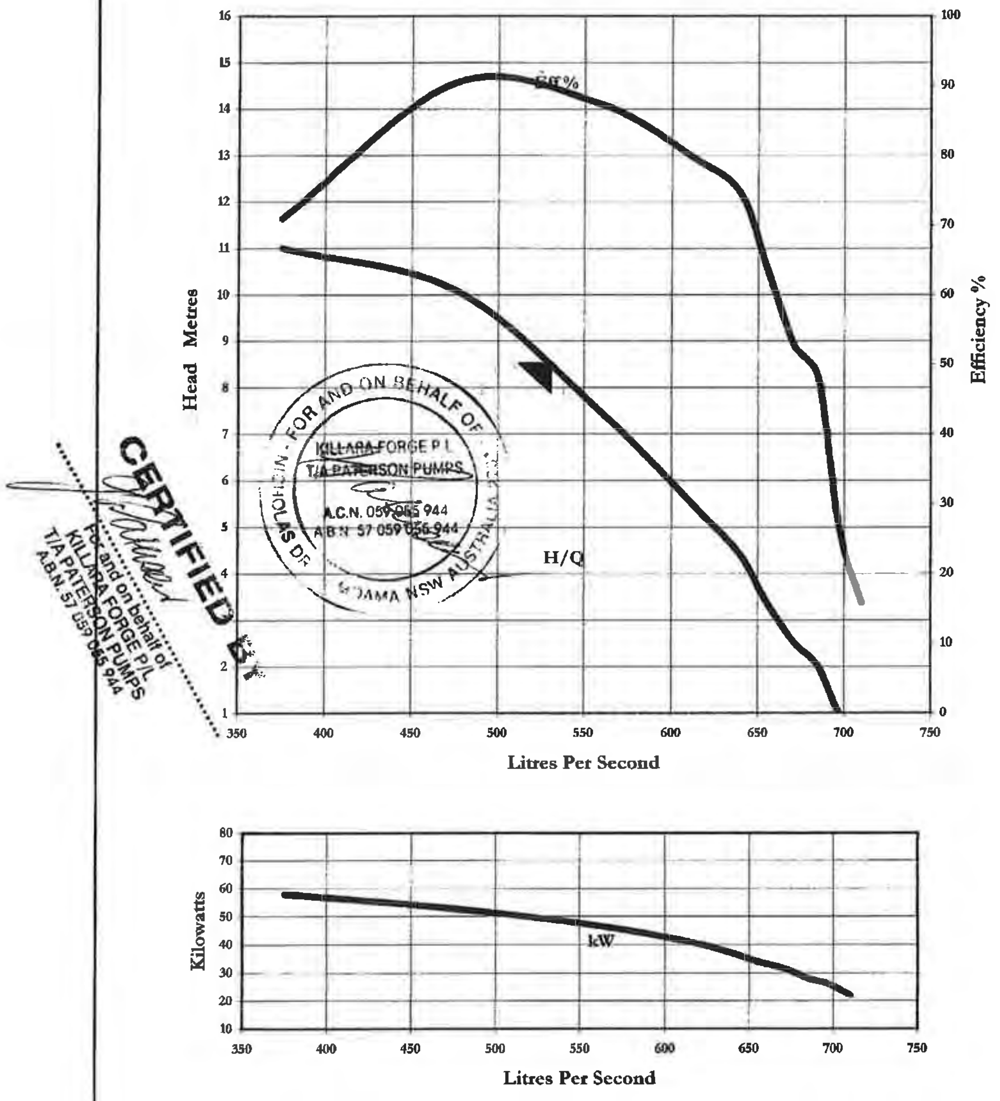
Yours Sincerely

John Paterson
Dip of Eng Technology

Paterson Pumps

2 Nicholas Drive, MOAMA, NSW 2731

Tweed Shire Council Contract No. EC2004-087a



No of stages	Effic. Change	Impeller Stainless Steel	Test No 15	Stage Performance
1		Bowls, Cast Iron	990rpm	S.N 737
		Pump diameter 610mm	Imp No4	

Paterson Pumps

2 Nicholas Drive, MOAMA, NSW 2731

Tweed Shire Council Contract No. EC2004-087a

No of stages 1

Initial RPM 200
Final RPM 990

Final performance Imperial

	Flow	Head	Hp	Efficiency
1	5022.00	36.20	77.72	0.709
2	6361.00	33.30	71.02	0.904
3	7365.20	24.69	63.00	0.875
4	8102.00	17.78	54.94	0.794
5	8437.00	14.48	49.58	0.747
6	8637.39	11.19	45.56	0.643
7	8850.00	8.30	42.21	0.527
8	9039.00	6.58	37.52	0.480
9	9200.00	3.29	34.84	0.263
10	9373.90	1.65	29.48	0.159

Final performance Metric

	Flow	Head	kW	Efficiency
1	375.00	11.00	58.00	70.88
2	475.00	10.10	53.00	90.38
3	558.28	7.52	47.00	87.46
4	614.13	5.42	40.99	79.43
5	639.52	4.41	36.99	74.67
6	654.71	3.41	33.99	64.29
7	670.83	2.53	31.49	52.73
8	685.16	2.01	27.99	48.04
9	697.36	1.00	25.99	26.33
10	710.54	0.50	21.99	15.90

FOR AND ON BEHALF OF KILLARA FORGE P/L T/A PATERSON PUMPS A.C.N. 059 055 944 A.B.N. 57 059 055 944 NICHOLAS DRIVE MOAMA NSW AUSTRALIA 2731

CERTIFIED BY

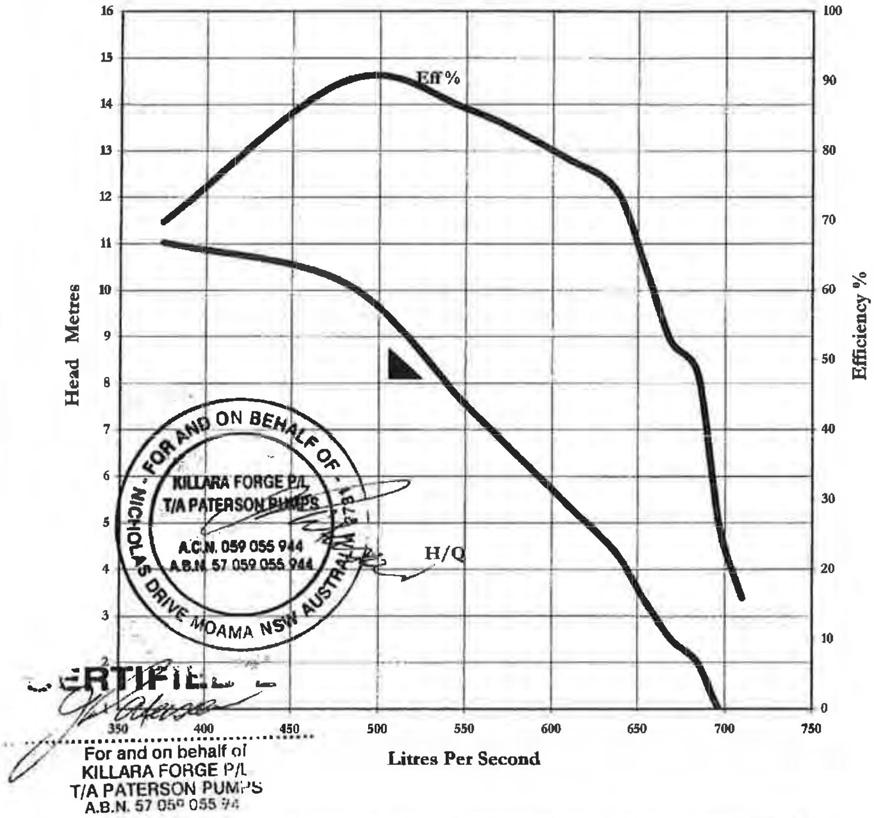
For and on behalf of
KILLARA FORGE P/L
T/A PATERSON PUMPS
A.B.N. 57 059 055 944

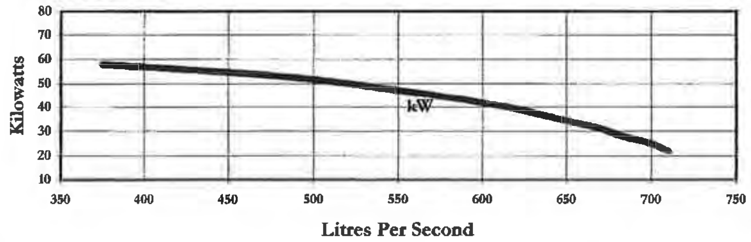
No of stages	Effic. Change	Impeller Stainless Steel	Test No 15	Stage Performance
1		Bowls, Cast Iron	990rpm	S.N 737
		Pump diameter 610mm	Imp No4	

Paterson Pumps

2 Nicholas Drive, MOAMA, NSW 2731

Tweed Shire Council Contract No. EC2004-087a





No of stages	Effic. Change	Impeller Stainless Steel	Test No 16	Stage Performance
1		Bowls, Cast Iron	990rpm	S.N738
		Pump Diameter 610mm	Imp No 4	

Paterson Pumps

2 Nicholas Drive, MOAMA, NSW 2731

Tweed Shire Council Contract No. EC2004-087a

No of stages 1

Initial RPM 990
Final RPM 990

Final performance Imperial

	Flow	Head	Hp	Efficiency
1	4950.00	36.20	77.72	0.699
2	6340.00	33.30	71.02	0.901
3	7265.00	24.69	63.20	0.860
4	8025.00	17.80	54.85	0.789
5	8395.00	14.45	49.32	0.745
6	8617.00	11.19	45.50	0.642
7	8825.00	8.30	42.11	0.527
8	9029.00	6.58	37.45	0.481
9	9191.00	3.29	34.75	0.264
10	9365.00	1.65	29.45	0.159

Final performance Metric

	Flow	Head	kW	Efficiency
1	375.21	11.03	57.98	69.87
2	480.57	10.15	52.98	90.08
3	550.69	7.53	47.15	86.01
4	608.30	5.43	40.92	78.92
5	636.34	4.40	36.79	74.53
6	653.17	3.41	33.94	64.22
7	668.94	2.53	31.41	52.71
8	684.40	2.01	27.94	48.07
9	696.68	1.00	25.92	26.37
10	709.87	0.50	21.97	15.90

FOR AND ON BEHALF OF KILLARA FORGE P/L T/A PATERSON PUMPS A.C.N. 059 055 944 A.B.N. 57 059 055 944 NICHOLAS DRIVE MOAMA NSW AUSTRALIA 2731

CERTIFIED BY

For and on behalf of
KILLARA FORGE P/L
T/A PATERSON PUMPS
A.B.N. 57 059 055 944

No of stages	Effic. Change	Impeller Stainless Steel	Test No 16	Stage Performance
1		Bowls, Cast Iron	990rpm	S.N738
		Pump Diameter 610mm	Imp No 4	

Appendix B

Historic Flood Photos

2008 Flood Photos

Knox Park

Looking north along Nullum Street from Price Street Intersection

Looking South along Nullum Street from Wollumbin Street Intersection

Elevated Tweed River Level at Lavender Creek outlet

Upstream of Lavender Creek Pump Station

Looking towards Stan Sercombe Oval from Nullum Street

2012 FLOOD PHOTOS

Looking east from intersection of Nullum & Condong Streets

Looking towards Knox Park from intersection of Nullum & Wollumbin Streets

Knox Park

Looking east towards Stan Sercombe Oval from Nullum Street

Proudfoots Lane

Proudfoots Lane

Near the intersection of Brisbane Street & Proudfoots Lane

Near the intersection of Brisbane Street & Wollumbin Street

Proudfoots Lane looking towards Nullum Street

Upstream of Lavender Creek Pump Station

2013 Flood Photos

Looking south from James Street towards Barrie Smith Hockey Centre

Looking North along Brisbane Street from Hartigan Street Intersection


Looking north-west from Brisbane Street and Condong Street Intersection


Looking north along Brisbane Street near Condong Street Intersection

Looking east towards Murwillumbah Community Centre from Nullum Street

Looking North along Nullum Lane from Prince Street

2014 Flood Photos


Elevated Tweed River Water Level at Lavender Creek Outlet


Upstream of Lavender Creek Pump Station


Looking north from Rabjones Oval


Knox Park

Nullum Street near Murwillumbah Community Centre looking north

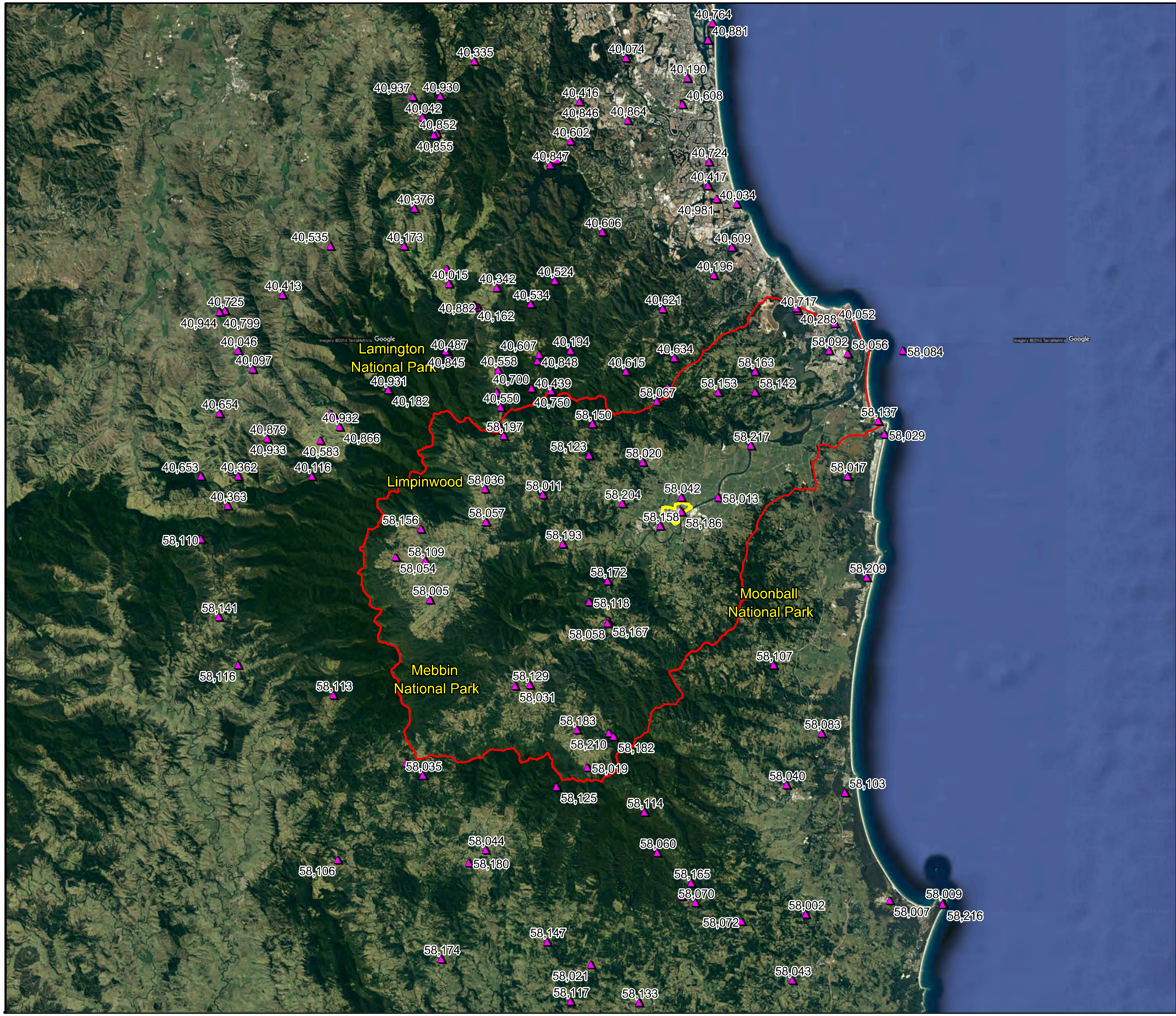
Knox Park

Lavender Creek looking west towards Bowling Club from Brisbane Street

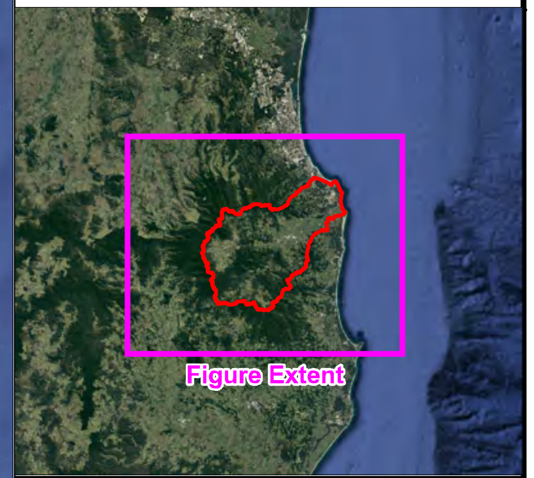
Nullum Street looking South from near Murwillumbah Community Centre

Appendix C

Historic Rainfall Information



TWEED SHIRE COUNCIL



LEGEND

- Daily Rainfall Gauge
- Catchment Boundary
- Study Area

Notes:

Aerial photograph date: 2015

N W E S

Scale 1:320,000 (at A3)

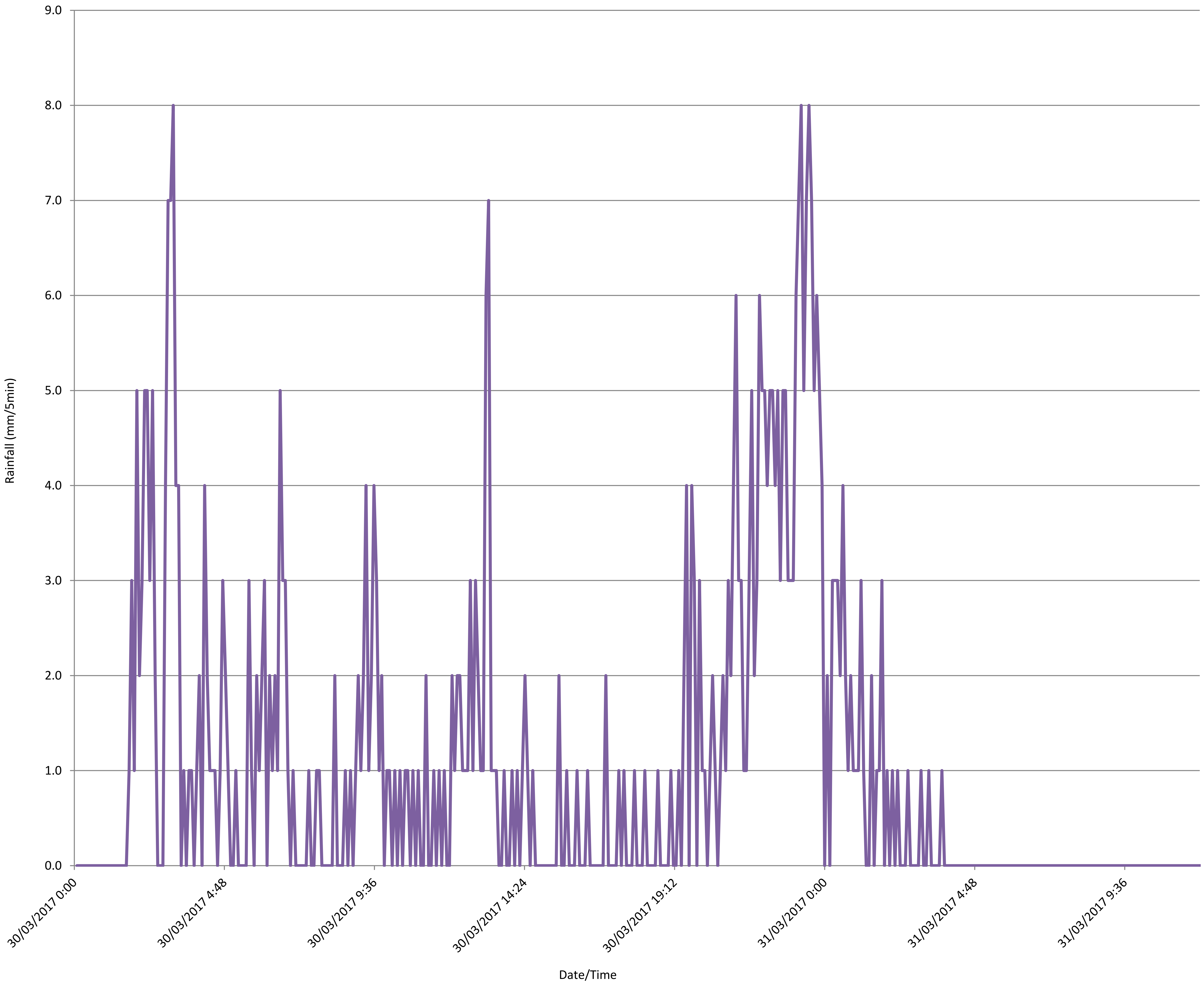
0 10 20 Km

Appendix C1: Rainfall Gauge Locations

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Rainfall Gauge Locations.wor



LEGEND:

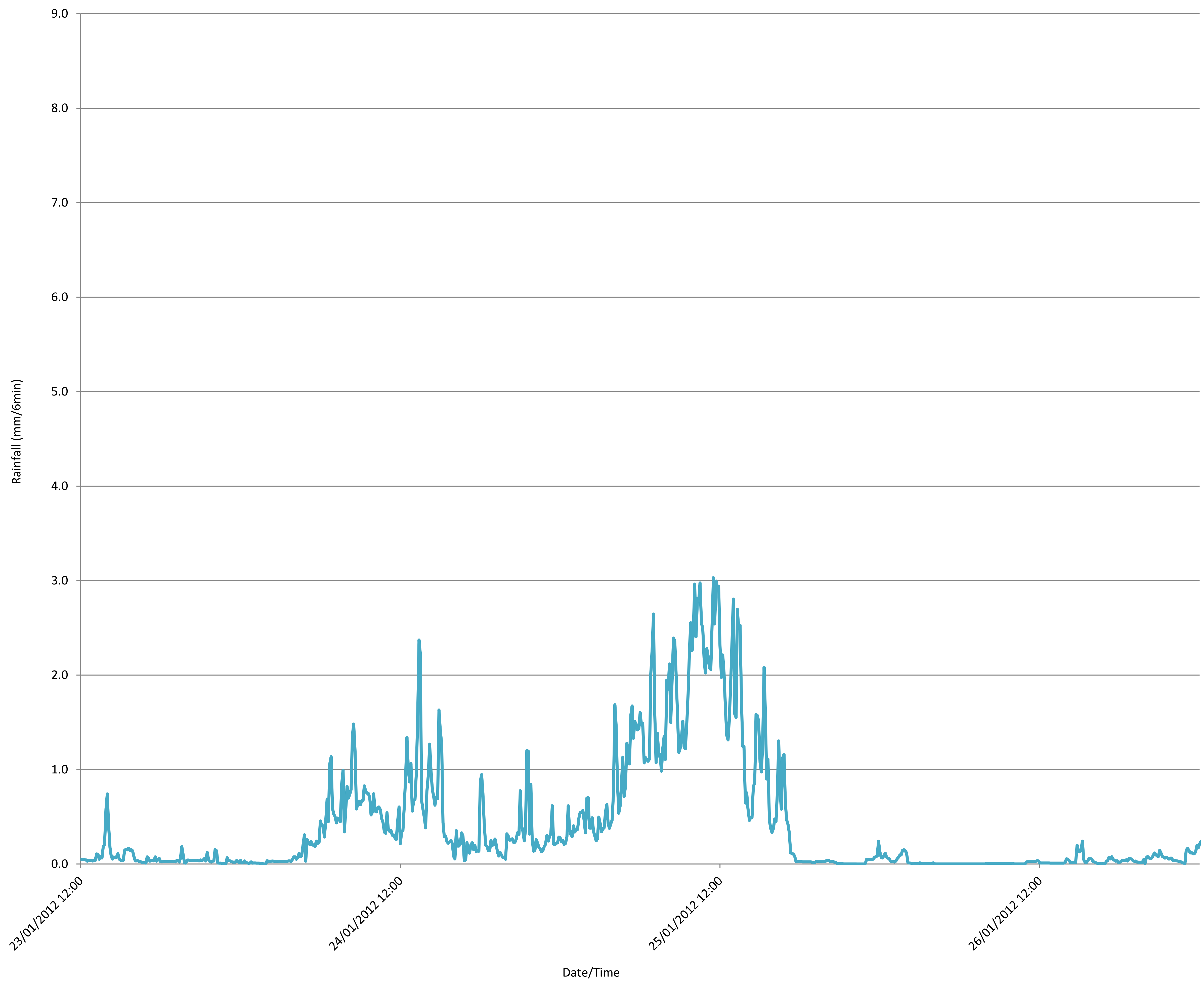
Murwillumbah

Notes:

Figure C2:
Continuous Rainfall Data for the March 2017 event

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: .xls



LEGEND:

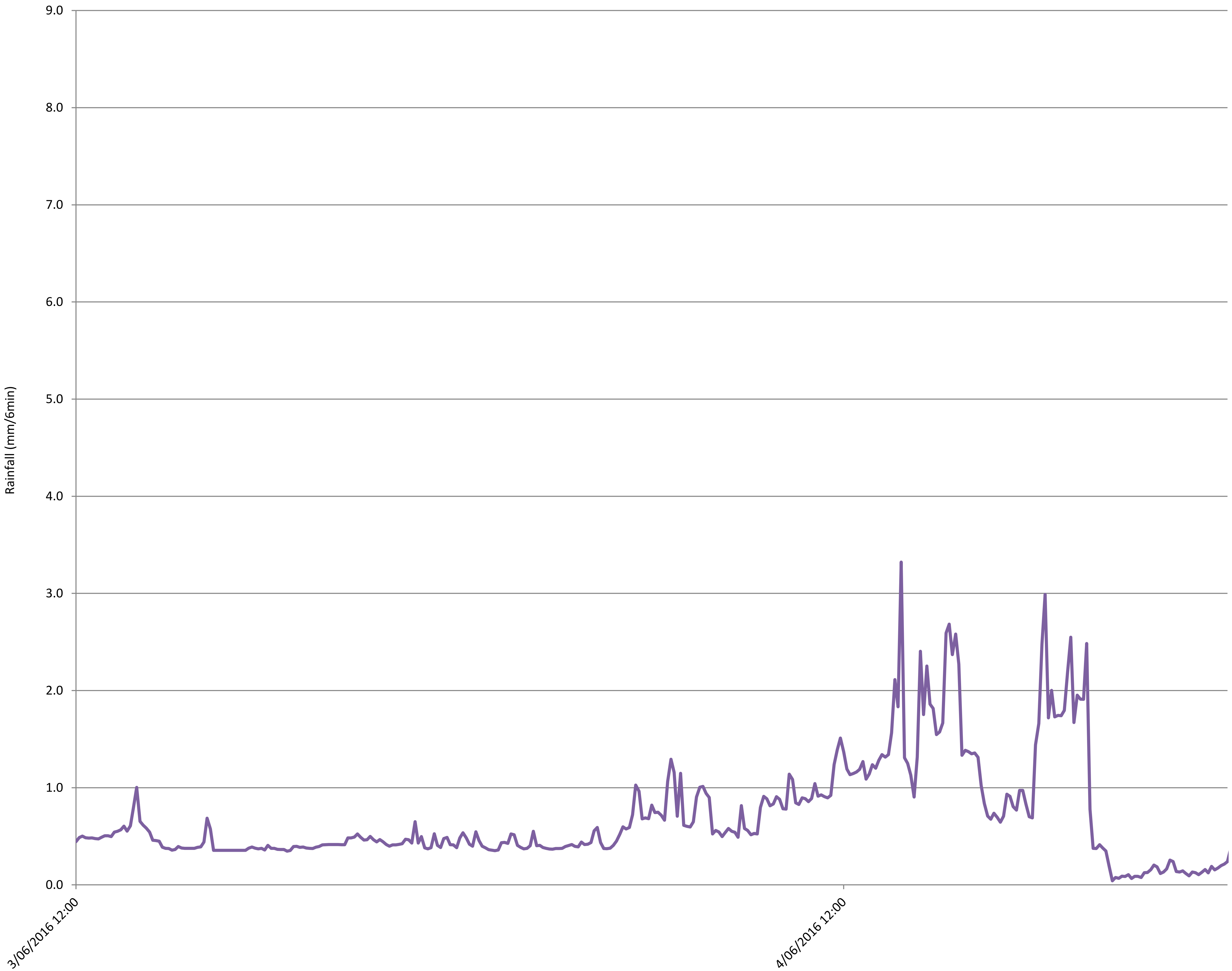
Murwillumbah

Notes:

Figure C3: Continuous Rainfall Data for the January 2012 event

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: .xls



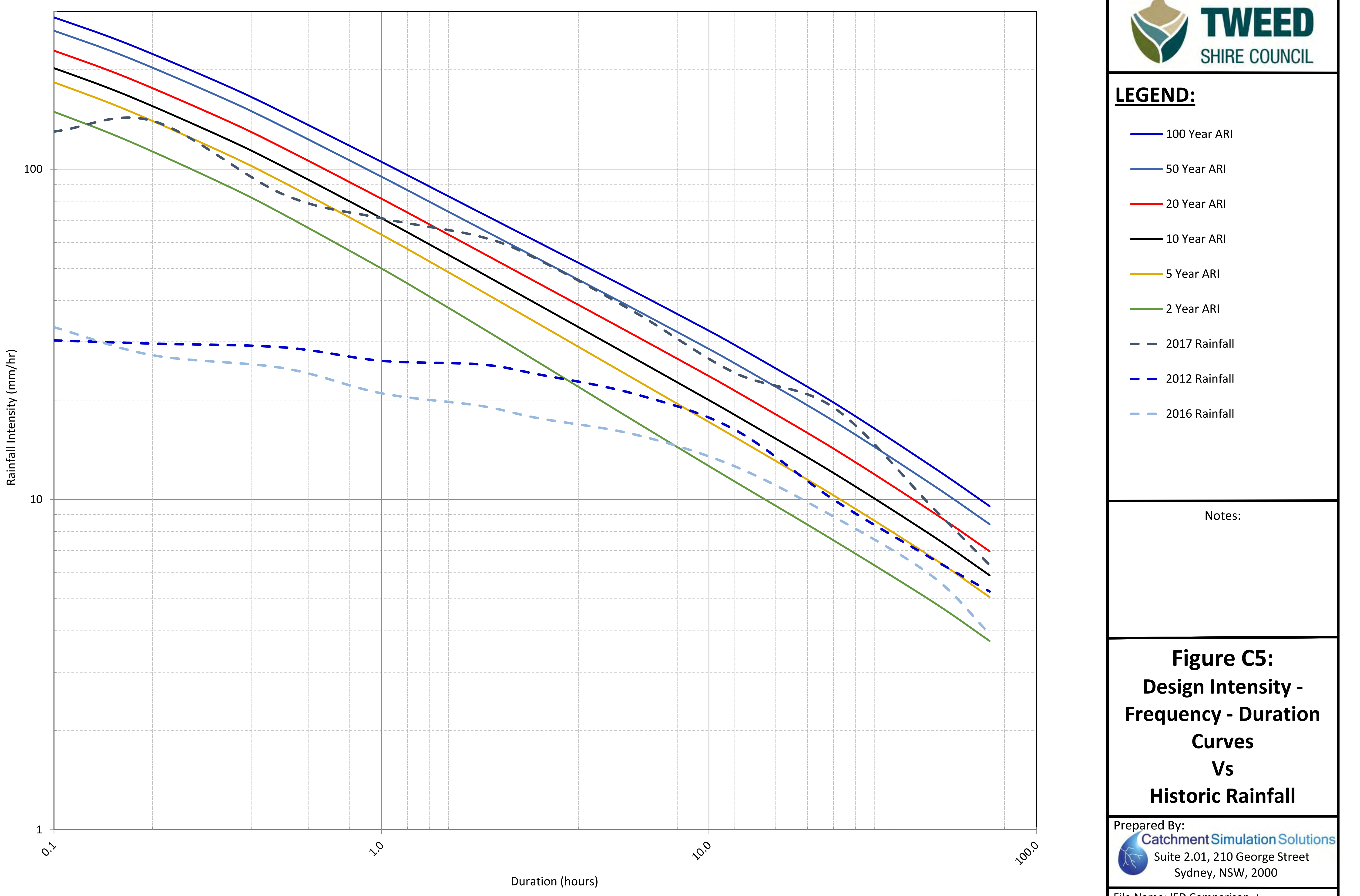
LEGEND:

Notes:

Figure C4:
Continuous Rainfall Data for the June 2016 event

Prepared By:
Catchment Simulation Solutions
Suite 302, 5 Hunter Street
Sydney, NSW, 2000

File Name: .xls



TWEED SHIRE COUNCIL

Notes:

Figure C5:
Design Intensity - Frequency - Duration Curves Vs Historic Rainfall

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George Street
Sydney, NSW, 2000

File Name: IFD Comparison.xlsx

Appendix D

2017 Flood Information

2017 Flood Photos

Corner of Wharf Street and Commercial Road (12:30am on 31 March 2017)

Commercial Road looking south from Sugar Beat Cafe (12:30am on 31 March 2017)

Corner of Tumbulgum Road and Commercial Road (12:30am on 31 March 2017)

James Street (9:30am on 31 March 2017)

Lavender Creek Pump Station (9:00am on 31 March 2017)


Lavender Creek Pump Station (3:00pm on 31 March 2017)


Water spilling across Commercial Road immediately south of levee (9:00am on 31 March 2017)

Brisbane Street near Proudfoots Lane (11:00am on 31 March 2017)

Elizabeth Street Sporting Fields (9:30am on 31 March 2017)

King Street (8:30am on 31 March 2017)

Knox Park (11:00am on 31 March 2017)

Shops near intersection of Nullum St and Wollumbin St (11:00am on 31 March 2017)


Prince St near Nullum St (11:20am on 31 March 2017)

3 George St (10:20am on 31 March 2017)

Intersection of William St and Thompson St (8:00am on 31 March 2017)

William St looking towards Everleigh St (1:20pm on 31 March 2017)

Looking towards Brothers Rugby League Club from Dorothy Street (1:30pm on 31 March 2017)


Murwillumbah Sewage Treatment Plant (1:30pm on 31 March 2017)


West End Street (1:15pm on 31 March 2017)

Looking down towards William St and Dorothy St intersection (1:30pm on 31 March 2017)

Intersection of William St and Dorset St (1:45pm on 31 March 2017)

Aerial view looking west towards Murwillumbah from South Murwillumbah (4 April 2017 - 30 hours after flood peak)

Aerial view looking east from Murwillumbah Sewage Treatment Plant (4 April 2017 - 30 hours after flood peak)

REPORT:

The Event

In late March 2017 Tropical Cyclone Debbie formed in the Coral Sea off North Queensland. On 28 March it crossed the Queensland Coast north of Mackay as a Category 4 system. Debbie weakened into a tropical low and turned south, causing widespread rainfall and flooding across Central and South East Queensland. Ex-Tropical Cyclone Debbie began to impact on the Northern Rivers early on the morning of Thursday 30 March, with heavy rain across the Tweed Valley.

Initial flood watches and warnings were issued by the Bureau of Meteorology (BoM) from Tuesday 28 March, indicating a high probability of moderate flooding at Murwillumbah and minor flooding at Chinderah. Initial forecasts suggested the Tweed Valley might receive 350mm over 30-31 March.

The Tweed Valley had received considerable rainfall only two weeks prior – many stations upstream of Murwillumbah recorded over 200mm on 15-16 March. This provided a heavily charged catchment with little or no available storage across the catchment to offset rainfall runoff.

Ex-Tropical Cyclone Debbie resulted in widespread and sustained heavy rainfall across the Rous, Oxley and Tweed Rivers throughout Thursday 30 March. Rainfall intensities peaked in the period between 11pm Thursday night and 2am Friday morning, after which the rainfall largely ceased.

The rainfall caused record peaks at many river gauges, including Uki, Chillingham, Murwillumbah and Tumbulgum. While there are localised variations, the intensity of the flooding in these areas was generally a 1% AEP (average exceedance probability) or 100 year ARI (average recurrence interval) flood, exceeding the previous 1954 benchmarks at Murwillumbah. Fortunately rainfall on the coastal catchments was generally moderate, and the system did not result in any appreciable storm surge or king tides. As such, the Lower Tweed and most Coastal Villages escaped significant flooding. The exceptions were the Burringbar and Crabbes Creek catchments which were badly flooded by intense rainfall on Thursday night, impacting the villages of Burringbar, Mooball, Crabbes Creek and Wooyung. Chinderah also experienced moderate flooding (a magnitude estimated at 30 year ARI), as the flood peak dissipated.

A summary of 24 hour rainfall totals, based on gauge averages, is provided in Figure 1 below.

Tweed Shire was declared a Natural Disaster Area by the Government on 31 March 2017.

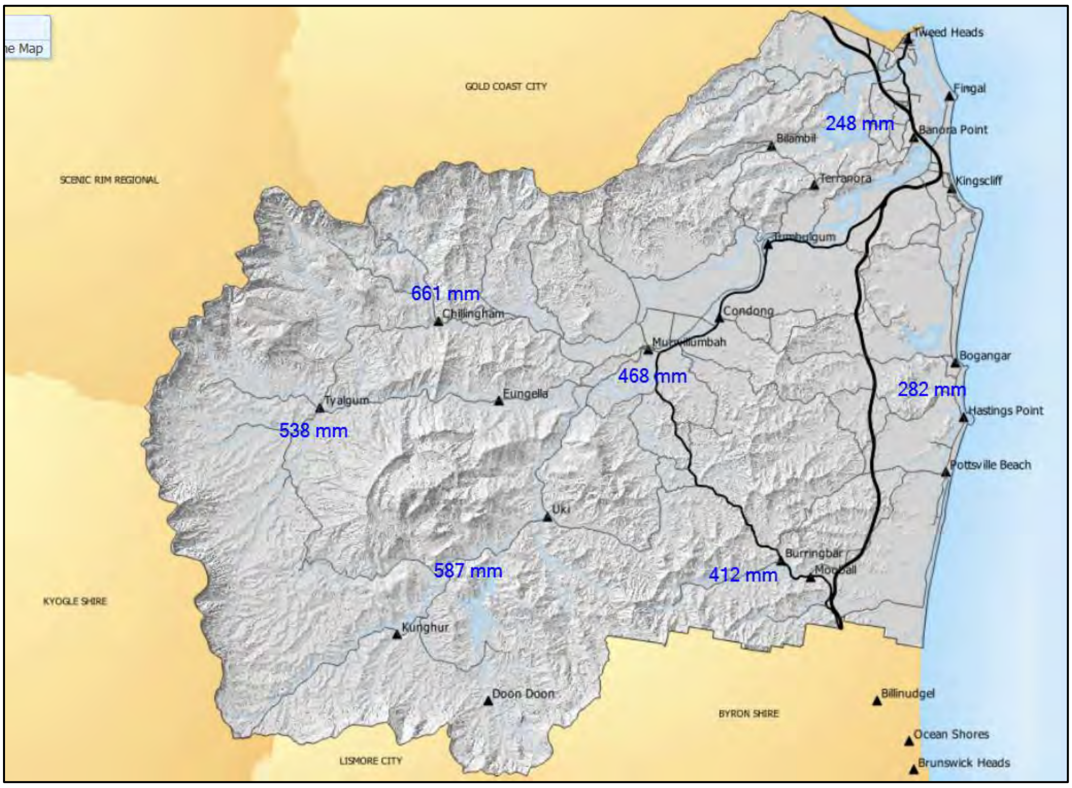


Figure 1 – 24 hour rainfall summary (local gauge averages) 30-31 March 2017

Event Observations

It is readily apparent that the weather event that caused such significant flooding was unpredictable and extreme. At midday on Thursday, despite heavy rainfall as the main weather system approached, flood warnings were still for moderate flooding in Murwillumbah. However by late afternoon the major flood level of 4.8m was exceeded in Murwillumbah, with water entering South Murwillumbah across Alma Street and then South Murwillumbah Levee. While this can occur in relatively small flood events (the levee provides approximately 20% AEP or 5 year ARI protection), the rapid escalation of warnings on Thursday afternoon left many residents and business owners unprepared.

The rate of rise across the upper catchments was rapid, and quickly cut main roads and bridges from Thursday morning. The flood peaks then moved quickly down the valley. River level hydrographs are provided for key gauges below, including comparisons of recent flood events, and where available, modelled peak levels from flood studies. The rapid rise of the flood is notable, as is the final peak due to the last burst of rainfall. Chillingham gauge has not been included as there were data errors in the gauge readings. Tumbulgum gauge also experienced data issues around the peak, but this has been corrected on the hydrograph below. A review of gauge performance is being conducted by the Office of Environment and Heritage (OEH).

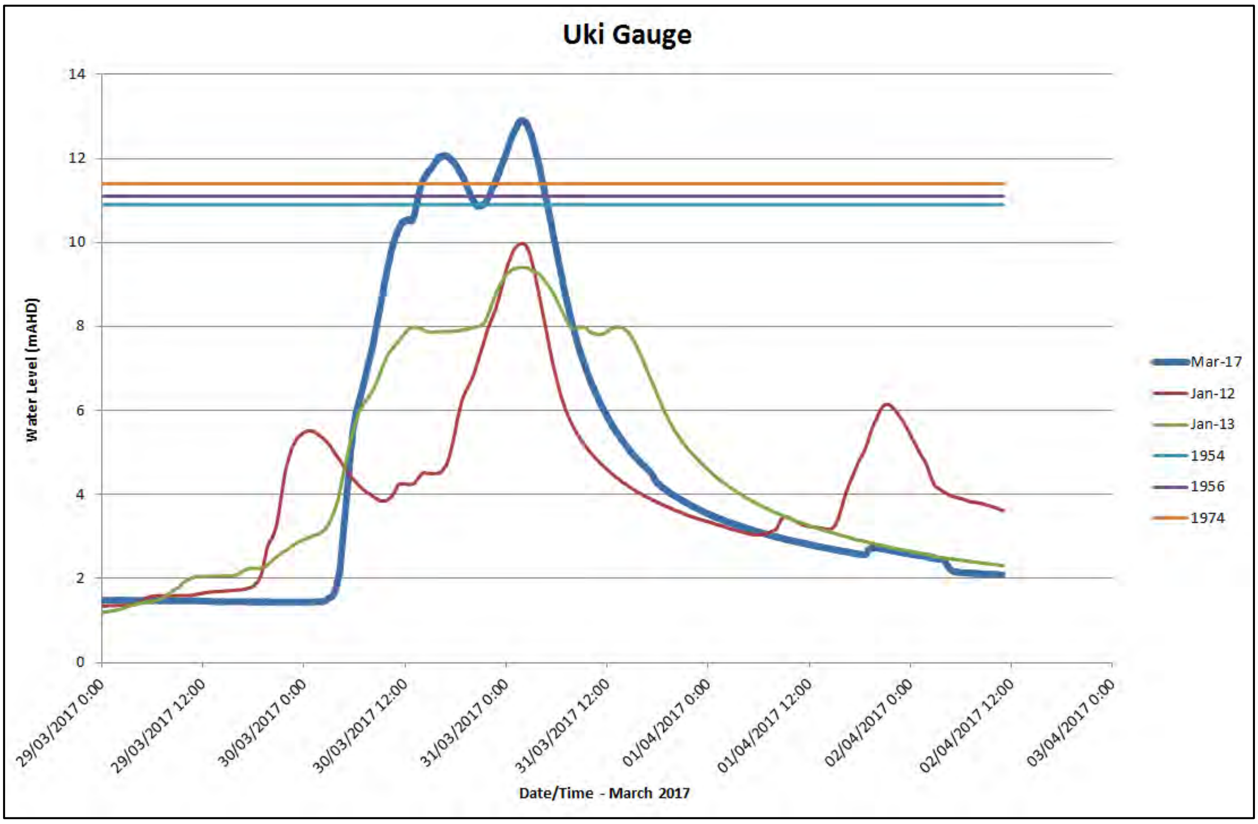


Figure 2 – River Gauge Readings at Uki

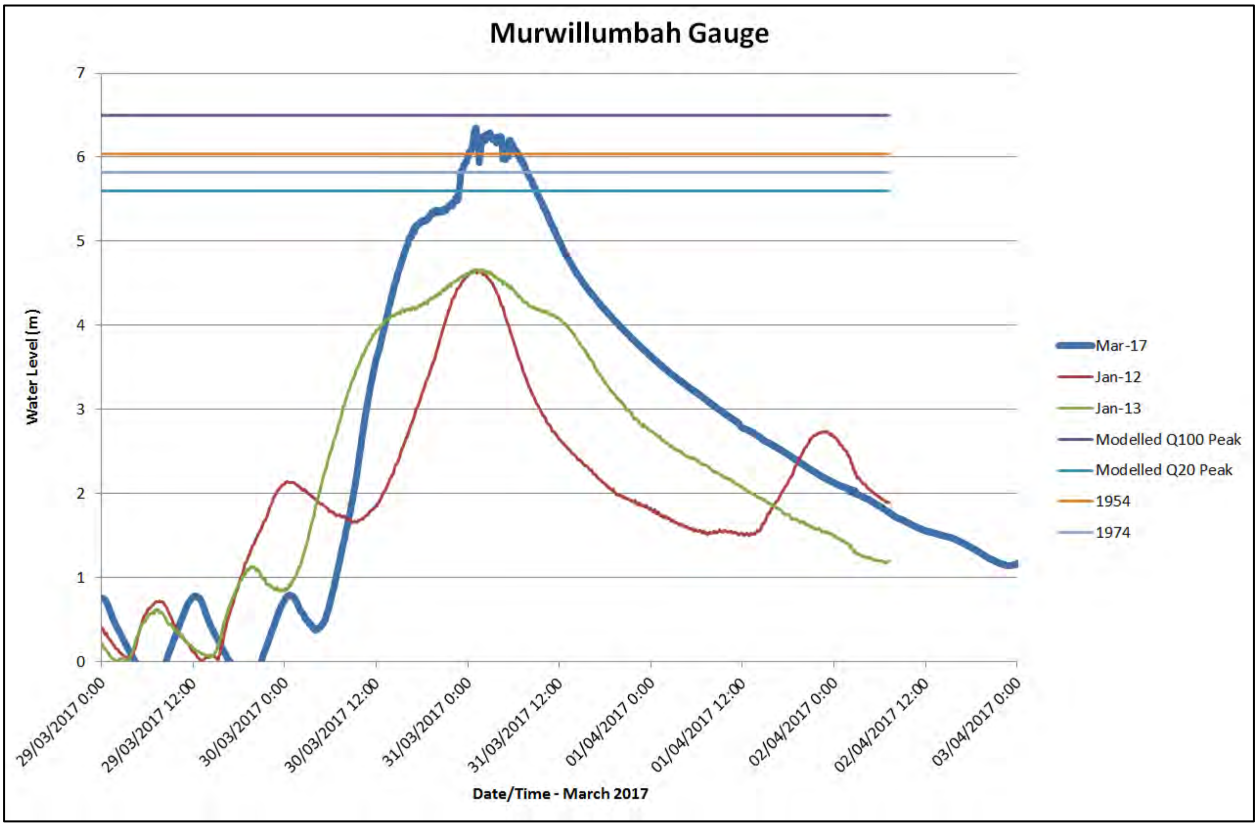


Figure 3 – River Gauge Readings at Murwillumbah (Bridge Gauge)

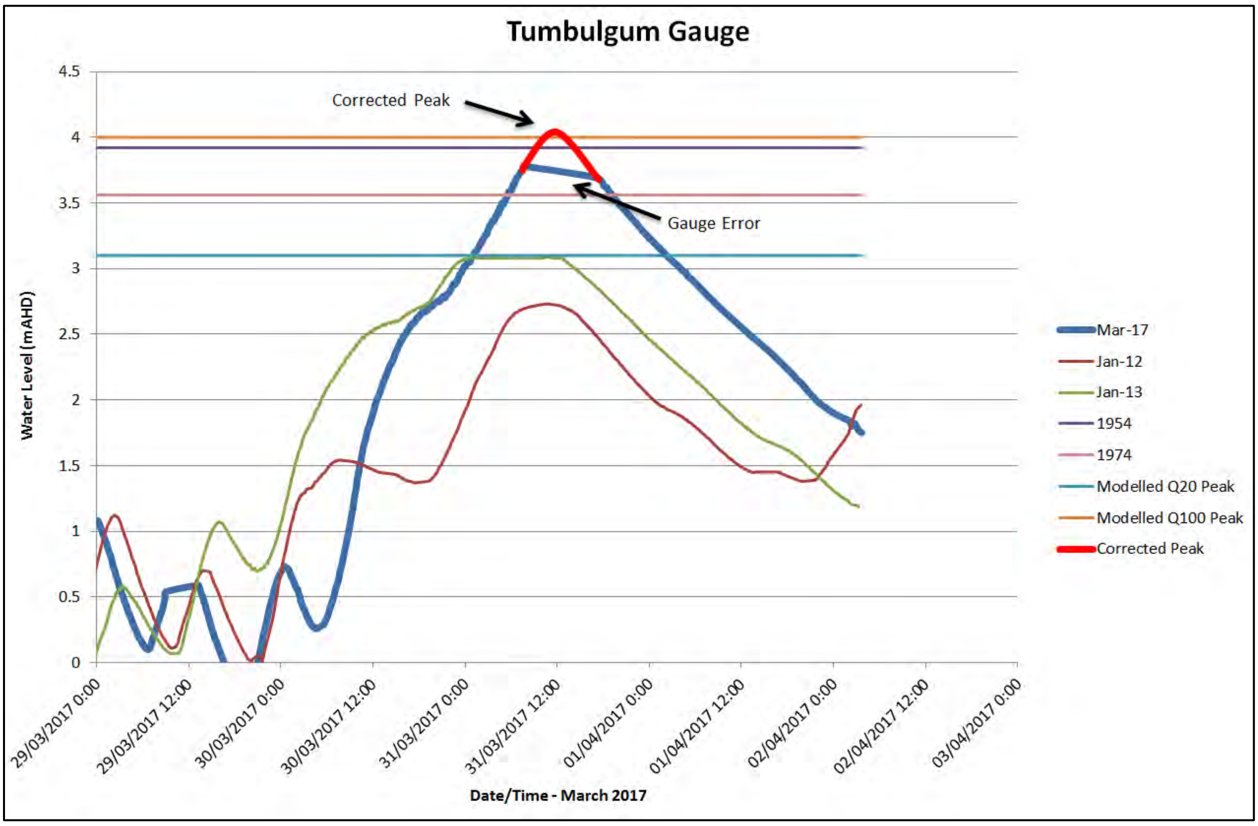


Figure 4 - River Gauge Readings at Tumbulgum (corrected)

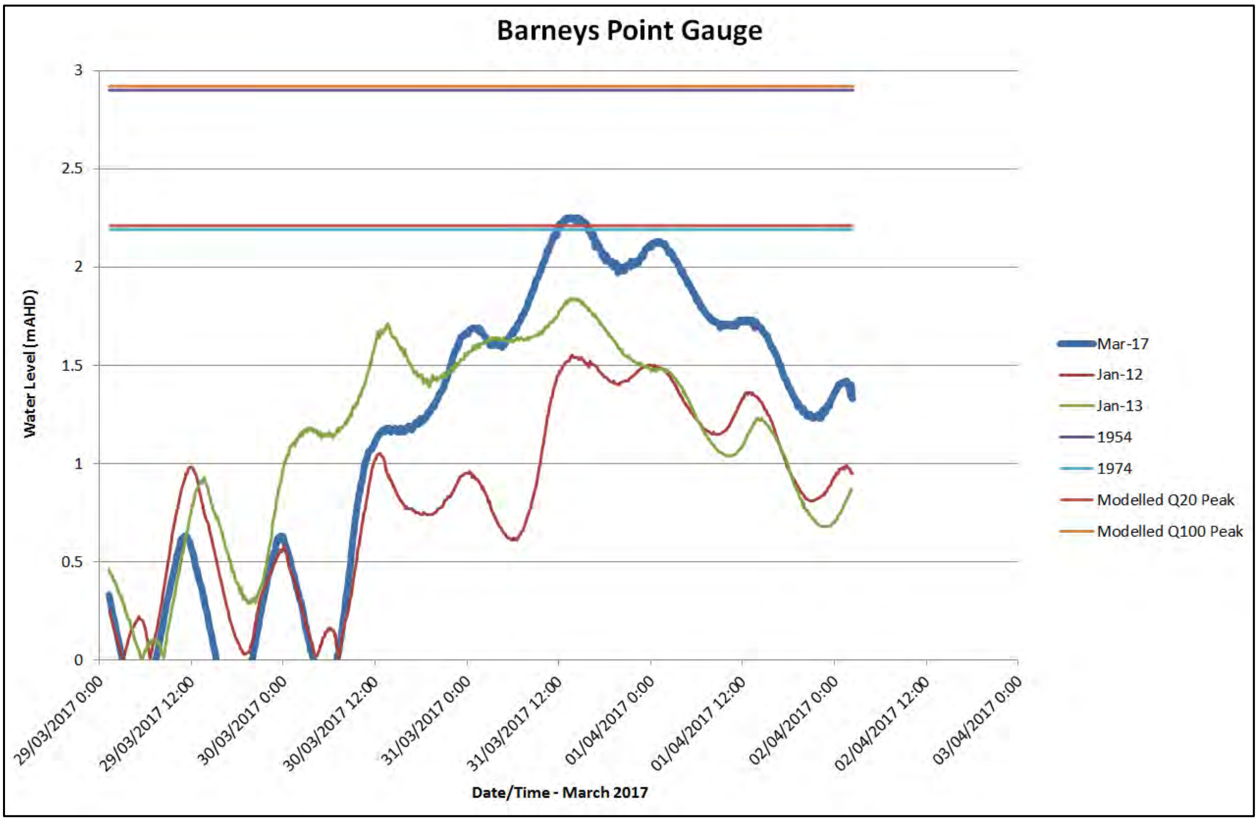


Figure 5 – River Gauge Readings at Barneys Point (Chinderah)

Event Impacts

The impacts of the flood event on residential communities, business and industry, and public infrastructure are widespread and severe.

First and foremost, this report acknowledges the deaths of six of our community members during the flood event, and recognises that the ongoing social costs of such losses far exceed the financial losses, and will stay with their family and friends forever.

Based on rapid assessment data obtained from NSW Fire and Rescue, approximately 2,100 houses were flooded across many areas, but particularly in Bray Park, South Murwillumbah, Condong, Tumbulgum and Burringbar. Even high set homes were inundated, but largely the impacts were from enclosed ground level rooms and property. Many of these areas would not have been approved. Over 18,000 tonnes of household waste was removed from flood impacted suburbs – more than 6 times our annual Shire-wide kerbside clean-up volume. It is apparent that many of these households were not insured and have limited means to recover from such losses.

Large numbers of businesses were inundated in South Murwillumbah, including Prospero Street, Greenhills, Buchanan Street and Quarry Road. Of note is the gradual change in land uses in commercial and industrial facilities in these areas over time. Industrial estates were approved several decades ago on known flood prone land, on the basis that they were more “flood compatible” than residential development. However modernisation and computerisation of many industrial processes, plant and equipment across a diverse range of businesses, including automotive, manufacturing, construction and food production, has increased the flood exposure of the South Murwillumbah industrial area significantly.

This includes Council facilities, specifically Buchanan Street Depot and the Bob Whittle Airfield in South Murwillumbah. Losses at the Depot comprised almost 30% of Council’s fleet, including trucks, small vehicles, workshop and stores. Estimates put the damage at $6.9M for plant and vehicles, of which $4.7M is expected to be recouped from insurance and the remainder from existing plant fund reserves. The administration building sustained over one metre of flooding over its floor level, and requires substantial refitting and refurnishing. Staff have been relocated to the vacant Coolamon Centre while repairs take place. The damage estimate for buildings and workshop equipment is approximately $800k which will form part of Council's $3.5M flood insurance claim.

There was a significant amount of debris, large and small, left in the river and along the river banks. Much of this debris is hazardous and has high potential to pollute. Submerged objects and the movement of large volumes of silt may also have implications on safe navigation in the river.

Infrastructure

The flood caused interruptions to significant water and wastewater infrastructure including Bray Park Water Treatment Plant, the raw water pump station at Bray Park, Tyalgum and Uki Water Treatment Plants, Murwillumbah and Mooball Wastewater Treatment Plants, the Tumbulgum Vacuum Sewer Station, and a very large number of sewage pump stations. Fortunately these services were able to be restored relatively quickly. The exceptions were: Tumbulgum Vacuum sewer system, taking 7 days to fully restore; River Street Wastewater Pump Station, taking 12 days to return to normal operation; and the Uki Water Treatment Plant which was not operational for 3 weeks and water was tankered from Bray Park. The Uki Water Treatment Plant has not been fully restored. It has been decided to bring forward the proposed water quality upgrade works and combine them with the restoration works now required.

A permanent water main connection is still required on Tweed Valley Way at Blacks Drain along with scour protection works for short sections of the trunk water main between Condong and Tumbulgum.

The dam spillway at Clarrie Hall Dam, which was upgraded in 2014, experienced a flow depth of 3.05m at the peak of the event. This triggered a white alert, the first of 4 levels of alert. The maximum spillway discharge recorded during this event was $355m^3$ per second, which is slightly above the 1% AEP predicted discharge flow rate. The spillway is designed to cater for the PMF flow rate of $1368m^3$ per second.

Road infrastructure experienced the most damage of any public asset group, with current estimates to repair the road network at over $23 million. Around 1500 road defects attributed to the flood were logged by engineering inspectors across 169 Council roads. A map showing the distribution of damage is provided below, along with a table summarising damage type and estimated costs. The most significant damages were the loss of the Byrrill Creek Road bridge on the Tweed River, which was torn from its piers, and severe bottom side slips on several roads including Clothiers Creek Road, Urliup Road, Cudgera Creek Road, Manns Road, and Lone Pine Road. The Tweed Valley Way road formation was destroyed by flood overtopping at Blacks Drain at Greenhills, taking with it essential services. Several weeks were spent removing top side slips and causeway washouts to restore access to isolated rural communities throughout the valley. The Pacific Highway was closed for two days (1-2 April) and Tweed Valley Way was closed until 3 April. Conditions on the roadways remained hazardous well after the water receded due to large amounts of debris and silt deposits, as well as surface damage.

DAMAGES MAP VIEW

Showing 1511 items on map and 0 with no Lat/Long.

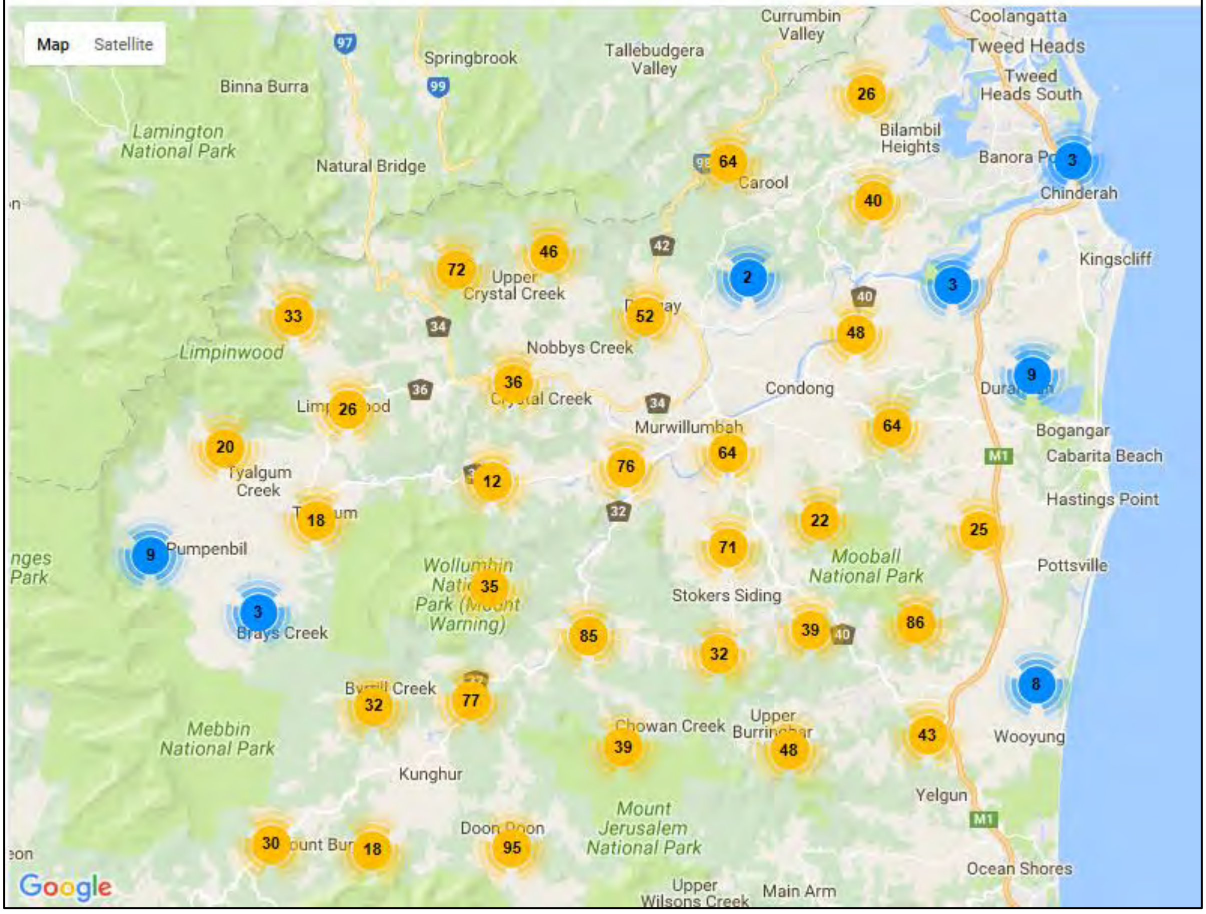


Figure 6 – Map View of Road Damages logged by Engineering Inspectors

MARCH 2017 FLOOD - PRELIMINARY ROAD REPAIR ESTIMATE			
ROADS	CAUSEWAYS	$1,643,389	$18,121,458
ROADS	EARTHWORKS/STRUCTURAL	$12,228,669	
ROADS	PAVEMENT	$3,381,794	
ROADS	FIXTURES	$328,466	
ROADS	CLEANUP	$539,140	
BRIDGES	NEW BRIDGE	$3,162,000	$5,183,400
BRIDGES	BRIDGE REPAIRS	$2,021,400	
OTHER INFRASTRUCTURE		$77,707	$77,707
TOTAL		**$23,382,565**	**$23,382,565**

Figure 7 – Summary of Road Repair Estimates by Type

Council's flood mitigation infrastructure performed well throughout the event. The Murwillumbah Levee protecting the Central Business District had not been seriously tested since it was raised to its current crest height in the early 1990s. Minor overtopping of the levee occurred at the upstream earthen section adjacent to Murwillumbah High School, but the levee maintained its integrity. The levee provides approximately 80 year ARI protection to the town and fortunately the river level at the bridge peaked slightly below forecast levels.

Flood pump stations at Lavender Creek and Wharf Street were operational throughout the event, however rainfall volumes from the local catchments exceeded their capacity and low level (but significant) flooding of homes and businesses in Main Street, Commercial Road, Brisbane Street, Wollumbin Street, Nullum Street and Condong Street occurred. The Lavender Creek Pump Station lost power early in the morning of 31 March, however this occurred after rainfall had ceased, and service was restored soon after.

East Murwillumbah Levee is designed at the 1% AEP level and experienced minor overtopping in the vicinity of Murwillumbah East Primary School. Dorothy Street levee was overtopped by about 300mm at the peak of the event, and combined with significant local catchment flooding around Brothers Leagues Club to fill this basin. The Leagues Club and several homes around William Street were impacted by this water. Peak water levels from this section of the Rous River appear to have exceeded 1% AEP levels in this event.

The South Murwillumbah levee was raised to its current level in the 1990s in conjunction with the Town Levee works, and provides approximately 5% AEP protection. It has successfully protected South Murwillumbah during various floods since, but was overwhelmed by the magnitude of this flood event. Overtopping initially occurred across Alma Street, and then various parts of the earthen levee. At its peak the levee was overtopped by around 2m of water. River flows caused major scour to the river side of the levee embankment. North of Colin Street, the levee formation breached when a large tree collapsed. Cost to repair the levee is estimated at $500,000. Water flows through South Murwillumbah towards the storage basin behind the industrial estate caused significant damage to properties, and eroded large sections of the railway embankment.

The Stotts Creek Resource Recovery Centre (SCRRC) was forced to open a new landfill cell specifically for the waste generated by the flood. The SCRRC is looking to process as much of the fill that has been deposited as possible and is actively chasing opportunities to reuse this material, however approximately 8,500 cubic metres of air space was used to deposit household waste.

Waterway assets along the Tweed River were badly damaged by the flood, particularly pontoons and boat ramps. The pontoons at Skinner Lowes Wharf, Murwillumbah and Condong Boat Ramp were dislodged and will require repair and replacement. Tumbulgum timber jetty was to be replaced and this will now be brought forward in the program as the structure was damaged. Most of the other waterways facilities required structural assessment and mostly minor repairs including silt removal from boat ramps. Fortunately coastal assets were largely unaffected.

Several recent riparian fencing and restoration projects, funded predominantly through the NSW Environmental Trust, were substantially impacted. Some of these sites have been repaired. While these recent sites were severely impacted, many other well-established riparian restoration project sites survived, demonstrating the value of well-maintained and robust riparian vegetation in maintaining stable river banks.

There was a significant amount of debris, large and small, left in the river and along the river banks. Contractors were employed for one week to clear as much as possible from the river banks and staff continue to collect debris from a boat.

Several Council buildings were impacted by flooding with various degrees of structural and non-functional damage caused to these assets, including treatments of mould growth and removal of asbestos containing material. Worst affected were the Print Makers in Bray Park, Nullum House (Knox Park) Murwillumbah, Condong Hall (Possums Preschool), and the Murwillumbah Visitor Information Centre, which has been temporarily relocated to the old railway station. A Council owned residential property at 341 Tweed Valley Way South Murwillumbah was completely inundated. Building repair costs and contents replacement are likely to exceed Council’s insurance cap of $3.5 million for the event.

Recreation Services sustained relatively minor damage to parks and sports fields, however some ancillary assets such as fencing, barbeques, amenities buildings and club houses were severely impacted. Bilambil Sports Complex was hit particularly hard - club houses were damaged, the carpark is no longer usable, and sports field fencing on both the east and west grounds were impacted. Total cost is estimated at over $100,000. At Tumbulgum two barbeque facilities and tennis court fencing were damaged, at a cost of over $20,000. Fifteen sports field amenity buildings were affected and the estimated cost to reinstate these buildings is $133,000. These costs have been incorporated into Council’s building report to the insurance assessor.

<u>Effectiveness of Preparations</u>

As described earlier, warnings for the flood event were in place several days prior, however in hindsight these warnings significantly under-estimated the magnitude of the flood that occurred. Council staff enacted their usual protocols of checking critical assets, confirming crew availability, dispersing plant and signage, and relocating high value items from low lying areas. In accordance with staff protocols, many staff left work to look after their families and their own properties by midday Thursday, when flood warnings were still for moderate flooding. However the weather system intensified in the evening and later through the night, leading to upgraded warnings for major flooding and peak levels that would see key facilities such as Buchanan Street depot inundated to depths not seen in living memory. Most businesses in the industrial area were similarly under-prepared for the magnitude of the flood.

There has been general community angst regarding the accuracy of BoM forecasts and warnings, and the NSW State Emergency Service (SES) response (including evacuations) around the March 2017 flood, particularly as these agencies are seen to be based “out of town”. While there is a key role for local flood intelligence networks in enhancing and verifying warning and response processes during floods and other natural disaster events, the roles and responsibilities of BoM and SES are legislatively based. Undue involvement by Council or other agencies in these roles will increase the risk of conflicting information, poor coordination of resources and ultimately poor decision making. Council will be involved in various post-event debriefs with all of the relevant agencies in due course, to improve preparations for future flood events.

Impacts on Council Operations

Council was fortunate that telecommunications and electricity remained largely unaffected by the event, and allowed recovery efforts to commence immediately following the flood peak.

Impacts of plant losses were mitigated by engaging contractors, hiring equipment and vehicles, and assistance from neighbouring Councils, including Gold Coast, Ballina and Coffs Harbour.

The flood event hit at a time where the revised Community Strategic Plan and its supporting documents (Delivery Plan, Operational Plan) were pending adoption. The disruption and cost of the flood will require adjustment of these plans. Similarly, Council’s ability to complete the 2016/17 Delivery and Operational Plans has been negatively impacted.

Various capital works projects now need to be brought forward, such as the replacement of Byrrill Creek bridge. In order to accommodate this, other projects will need to be deferred. Similarly, programmed maintenance for a range of assets has been delayed or reallocated to reactive works.

A summary of proposed impacts is included in the Budget Section of this report.

Strategic Responses to the Flood

Council is fortunate to have a well advanced floodplain risk management process in place for the Tweed Valley and Coastal Creeks floodplains. Council has completed various flood studies and floodplain risk management studies across these areas over the last 13 years, at considerable expense and with assistance from the State Government. Observed flood behaviour in this event was generally in accordance with the outcomes of these studies, which is reassuring. The Office of Environment and Heritage (OEH) is commissioning a review of flood studies in the Tweed and Lismore areas using recorded information from the March 17 event.

These studies have helped to shape our flood related development controls, and many contemporary developments in badly affected regions escaped with minimal damage from the natural disaster. Examples including the Uki Hotel and the Murwillumbah IGA. These controls also provide Council with the framework to prevent an escalation of flood risk for future development, by setting rules for the rezoning of land and considering factors such as the cumulative impacts of filling, and designing evacuation capability into subdivision design in our major land release areas.

For those areas where there is residual flood risk due to historic settlement patterns, legacy land zonings, and lack of adequate building controls at the time of development, the Tweed Valley Floodplain Risk Management Study Plan (2014) and the Tweed Coastal Creeks Floodplain Risk Management Plan (2015) make a number of recommendations for priority actions. These have been extremely valuable in providing a coordinated and strategic approach to identifying projects for funding opportunities from higher levels of government in the flood aftermath.

For example, applications for the 2017-2018 round of OEH Floodplain Management Program grants closed on 27 April. Council officers were able to reference these plans in identifying the following projects for potential funding:

- Voluntary House Purchase in South Murwillumbah and Bray Park
- Voluntary House Purchase in Burringbar, Mooball and Crabbes Creek
- Voluntary House Raising in South Murwillumbah and Bray Park
- Voluntary House Raising in Burringbar and Mooball
- Flood Warning System to upgrade Tumbulgum Gauge for forecasting by the BoM
- Flood Warning System to install additional river and rainfall gauges upstream of Burringbar and Crabbes Creek.
- Flood study for South Murwillumbah basin to identify obstructions to flow, examine levee overtopping, and recommend floodway improvements

These applications were endorsed by the Floodplain Management Committee at the 28 April meeting. These projects have the potential to significantly reduce flood risk exposure for people and their properties, enhance warning times in flash flood catchments, and remove obstructions to flood flow in the worst affected areas.

Council's Executive has also made representation to State and Federal Government about potential projects to reduce flood risk in other flood impacted areas (such as widening the voluntary house purchase and raising schemes to other suburbs such as Condong and Tumbulgum which were not subject to recommendations from the Floodplain Risk Management Plans) and for works that are generally not eligible under the OEH grant criteria (such as modifications to commercial and industrial land to reduce flood risk).

Regarding the latter, the impacts of the flood on the South Murwillumbah industrial estate were extensive, to the point where some businesses may not be able to fully recover. This will impact on the local economy and employment. This area is also important for the passage of large volumes of flood water from Greenhills to Condong, however many of these industrial developments obstruct flows with fill pads, buildings and fences. In an ideal situation, given the availability of flood free land in close proximity in South Murwillumbah along Quarry Road and Wardrop Valley Road, a scheme to relocate many of these businesses to remove their flood risk as well as improving flood behaviour in these floodways would be a sound investment. However there is a large upfront capital cost that Government could provide in order to invest in flood mitigation rather than flood recovery. Floodplain Management Australia (FMA) suggests that in Australia Governments invest only $1 in preventative schemes for every $10 spent on flood recovery. Generally this involves putting infrastructure and development back in the same high risk situations.

Other Initiatives

Council staff responded in various innovative ways to the flood emergency, in order to work swiftly, compassionately and pragmatically to assist impacted individuals. Many will have ongoing benefits to the organisation for daily operations as well as enhancing our ability to connect with community. Examples include:

Social Media
During the flood event Council's Facebook page was deployed – our first official presence on social media. It was clear throughout the flood emergency that social media is integral to modern communication across a broad cross section of our population. Council's Facebook page was followed by 1786 people within a week of the flood, with 72,612 post engagements and 12,000 views of Council's videos. Social media (Facebook and Twitter) allowed Council to disseminate urgent and important information to the community for the first time. Social media also provided a platform to launch the Tweed Shire Mayoral Flood Appeal, particularly targeting Brisbane, Sydney, Melbourne and Canberra to capture people who had seen the floods on the news and wanted to assist in some way.

Data Collection
Council engineering staff employed new mobile solutions consisting of android devices connected to our asset management system to rapidly identify, photograph and catalogue around 1500 road and drainage defects across the Shire post-event. This will assist claims for Natural Disaster funding, but also enables upskilling of staff for wider application for non-flood customer work requests.

Building and Environment Inspections
The Building and Environmental Health Unit were some of the first responders to impacted communities at the start of the recovery phase, offering immediate and detailed assessment of residential and commercial building damages, at no charge. This prompt and professional action was widely praised and helped people prioritise works to get back into their homes and businesses.

Building surveyors undertook preliminary assessments to determine the extent of any structural damage and liaised directly with geotechnical experts on a priority basis which facilitated a rapid assessment where needed. For some elderly residents this provided important assurance that their home was safe to occupy. In other cases illegal structures were being built/repaired in the flood zone before the mud had even been cleaned up.

Environmental Health Officers spoke with business owners in all impacted towns on the Monday and Tuesday with practical advice on food disposal, asbestos, hazardous waste and other challenges, at a time when these business owners felt completely overwhelmed. The team also provided technical advice on health impacts of sewage spills in Tumbulgum to the Water and Waste Water Unit and later with enquires about health impacts of mould.

Support for Local Businesses
Council's Economic Development Unit provided critical support for flood impacted businesses in the immediate aftermath of the flood. The Business Facilitation officer established connections with the business community on the ground and via the newly opened social media channels, to assess their immediate needs. Officers alerted and briefed various Government Departments and communicated these contacts to those in need.

Skip bins were delivered to specific businesses who had an urgent need for removal of rotting food products. Officers also liaised with the FRNSW Hazardous Materials Response Unit to assist business in the industrial estates.

The face to face support was vitally important to businesses in the first two weeks of the recovery. It sent a clear message of 'Tweed Council's cares about you and we are here to help you through this'. This message was, and continues to be comforting to many business owners. Officers left business cards with direct contact details acting as a conduit from business into Council, taking a 'no wrong door' approach. This was appreciated, with many business owners taking up the offer of help.

The Economic Development Unit also worked strategically, preparing reports to assist in the activation of Category C funding for small business, organising Ministerial meetings with business owners and liaising with Government Departments and agencies to deploy on ground support mechanisms.

Emergency and Evacuation Support

Council provided a range of responses to assist the community during the establishment of the evacuation centres. Almost 100 people that were camping at Greenhills Caravan Park and elsewhere in Murwillumbah area were relocated to the Tweed Regional Gallery and Council allowed the use of the undercover car park and the facilities at the Artist in Residence Studio whilst the waters receded and alternative arrangements were made.

Council's Community and Cultural Services Unit produced a register of local services that were offering volunteer support, donations and could assist people during the flood. This list was then maintained on a daily basis and distributed online, to emergency services, and through the disaster recovery centre.

Officers undertook inspections of Council community halls, preschools, and other community buildings to assess the level of damage, and commence support for those services.

Establishment of Recovery Centre

The Community and Cultural Services Unit undertook initial assessments to identify a suitable site for the establishment of the Disaster Recovery Centre which the Office of Emergency Management set up following the closure of the official Evacuation Centres. The Murwillumbah Community Centre building was not inundated and a section of the building was well designed to meet the needs of the State and Commonwealth Government services that are established once a natural disaster is declared. The Information Technology Unit assisted with setting up the communications, hotline, and printers at the centre. The Community Development team recruited Disaster Recovery Centre staff, intake and administration officers, and security officers to manage the centre during the more than seven weeks of operation. The team also supported the centre on a roster during the first two weeks to ensure that someone with local knowledge assisted with referrals to local services.

The administration of the centre also involved monitoring the gaps in services that were identified at the centre, ensuring that the statistics and communications about the centre were monitored to inform responses locally and decisions about the centre's operational hours. From 6 April to 26 May 2017, over 1,761 people registered at the Disaster Recovery Centre.

Homelessness and Housing
One of the most significant issues arising for the community has been homelessness and housing. This is has been exacerbated by the pre-existing high need for accommodation for people that are homeless and for affordable housing options in Tweed Shire. It has been difficult to ascertain the extent of the issue, and the data to identify how many people have been displaced by the floods is collected by the State Government through the Recovery Centres and by the Department of Housing. Caravan Parks were also inundated with Greenhills Caravan Park, Wooyung Caravan Park, and three caravan parks in Chinderah all sustaining extensive damage. It was estimated that of those registering at the recovery centre during the period of 6 April to 9 May, over 200 people were staying in temporary accommodation.

Mental Health
The care of the volunteers and service providers that have been supporting the local community for over six weeks at this time is of concern. To provide suitable support for the mental health and wellbeing of the community a hotline and service was established by the Primary Health Network locally. The Community Development team at Council also worked with the Red Cross to facilitate a number of workshops for volunteers to debrief and check on their wellbeing. Additional workshops will be facilitated if required.

Long Term Recovery Plan development
The Community and Cultural Services Unit has worked with the Disaster Recovery Coordinator to design a needs assessment to inform the long term recovery plan for the region. This included an online survey that the Southern Cross University is analysing and three focus groups on housing and homelessness; mental health and wellbeing; and community and neighbourhood centre services. This collaboration between Tweed Shire Council, Lismore City Council, Byron Shire Council, and NSW Health has also included the development of a shared data base for ongoing communications during the recovery phase.

OPTIONS:

This report is provided for information of Council.

CONCLUSION:

The flood of March 2017 was an historic event for the Tweed, with wide reaching and long term impacts. This report aims to document these impacts, to help the community to understand their susceptibility to natural hazards, and to hopefully assist preparations for events in the future.

COUNCIL IMPLICATIONS:

a. Policy:
Corporate Policy Not Applicable.

b. Budget/Long Term Financial Plan:
The March 2017 flood has significantly disrupted Council’s ability to deliver many of the projects that were adopted in the 2016/2017 Delivery and Operational Plans and Organisational Key Performance Indicators (KPIs). Many projects will be deferred by necessity, due to resource changes and reduced capacity, others due to the need to set aside contingencies in the budget to cover as yet undetermined costs of the flood.

Projects to be deferred from 2016/2017 to 2017/2018 include:

- DCP-A5 Subdivision Manual update (KPI)
- Road and drainage upgrade, Gray Street Tumbulgum
- Kerb and guttering, Elizabeth Street Pottsville
- Road and drainage upgrade, Kirkwood Road and Philp Parade Tweed Heads South
- Kerb and guttering, Thomson Street Tweed Heads
- Drainage upgrade, Reynolds Street Murwillumbah
- Drainage upgrade, Nullum Street Murwillumbah
- Waterways repair projects including Foysters Jetty abutment; Sunset Boulevard revetment; and Mooball Creek log wall.

Further, as reported to Council in its consideration of the draft 2017/2021 Delivery Plan and 2017/2018 Operational Plan in April 2017, ***changes may need to be made to Council's capital works program/significant projects and service levels that have been listed in the Draft Delivery Program.***

The impacts of the flood will flow on into next financial year and beyond. Some projects will need to be brought forward as they have become urgent due to flood damage (for example, replacement of Byrrill Creek Bridge), others will be deferred, and others will be re-scoped. These will be subject to future reports associated with Quarterly Budget Reviews and operational reporting as these impacts become known.

As the flood event was a Declared Natural Disaster, Council is eligible for financial assistance towards the restoration of essential public assets under Natural Disaster Relief and Recovery Arrangements (NDRRA). The majority of NDRRA funding is provided by the Commonwealth Government and administered by the States. In NSW the Office of Emergency Management oversees the NDRRA which is implemented by NSW Public Works and Roads and Maritime Services.

NDRRA assistance is generally provided for road, stormwater drainage and flood mitigation assets. However other asset groups are ineligible, including recreation services, waterways and coastal assets, insured buildings, and business undertakings such as water and wastewater, airfields and saleyards. Ordinary Council wages and plant and equipment costs are also ineligible, meaning that Council will have to rely on contractors to undertake most flood repair projects. Fortunately Council received a special exemption to cover the costs of the roadside clean-up of flood waste, which was considerable. Council officers are preparing initial applications for NDDRA to the relevant agencies.

c. Legal:

Not Applicable.

d. Communication/Engagement:

Inform - We will keep you informed.

The flood provides a good opportunity to reinforce to the community key messages around flood preparedness, awareness of individual flood risk, and town planning controls. Development of a flood related communications strategy, in conjunction with the SES will be a key consideration of the Floodplain Management Committee at its next meeting.

One key message is that while the March 2017 flood was the largest flood seen in many locations, it occurred from a relatively short duration storm event, and a far greater flood is possible.

APPENDIX E

HISTORIC FLOOD MARK COMPARISONS

Table 1 2017 Flood Mark Comparisons

Surveyed Flood Mark Elevation (mAHD)	Simulated Water level (mAHD)	Difference (m)	Comments
7.75	7.6	-0.15	
6.26	6.25	-0.01	
5.83	5.77	-0.06	
5.82	5.77	-0.05	
5.79	5.65	-0.14	
5.7	5.74	0.04	
5.68	5.58	-0.1	
5.68	5.65	-0.03	
5.66	5.75	0.09	
5.49	5.26	-0.23	Surveyed flood mark elevation much higher relative to adjacent flood mark of 5.29m AHD
5.41	5.35	-0.06	
5.41	5.38	-0.03	
5.4	5.31	-0.09	
5.36	5.31	-0.05	
5.36	5.32	-0.04	
5.3	5.29	-0.01	
5.29	5.29	0	
5.29	5.26	-0.03	
5.29	5.73	0.44	Flood mark elevation inconsistent with adjacent flood marks of between 5.6 and 5.8m AHD
5.25	5.29	0.04	
5.17	5.29	0.12	Inconsistent with ponding elevation in local area of ~5.3mAHD
5.13	5.29	0.16	Inconsistent with ponding elevation in local area of ~5.3mAHD
5.09	5.29	0.2	Inconsistent with ponding elevation in local area of ~5.3mAHD
5.07	5.29	0.22	Inconsistent with ponding elevation in local area of ~5.3mAHD
5.02	5.3	0.28	Inconsistent with adjacent flood mark of 5.41mAHD
4.94	5.29	0.35	Inconsistent with adjacent flood mark of 5.30mAHD
4.72	4.93	0.21	
4.71	4.76	0.05	

Surveyed Flood Mark Elevation (mAHD)	Simulated Water level (mAHD)	Difference (m)	Comments
4.54	4.53	-0.01	
4.5	4.54	0.04	
4.39	4.53	0.14	Inconsistent with adjacent flood mark of 4.50mAHD
3.86	3.85	-0.01	
3.82	3.84	0.02	
3.81	3.84	0.03	
3.81	3.8	-0.01	
3.81	3.79	-0.02	
3.8	3.77	-0.03	
3.8	3.76	-0.04	
3.8	3.82	0.02	
3.79	3.77	-0.02	
3.79	3.82	0.03	
3.78	3.77	-0.01	
3.78	3.79	0.01	
2.47	3.77	1.3	Significantly lower than adjacent flood marks of ~3.8mAHD

Table 2 2012 Flood Mark Comparisons

Surveyed Flood Mark Elevation (mAHD)	Simulated Water level (mAHD)	Difference (m)	Comments
4.03	4.11	0.08	
3.86	4.11	0.25	
3.75	3.84	0.09	
3.41	3.53	0.12	
3.28	3.39	0.11	
3.17	3.19	0.02	
3.14	3.20	0.06	
3.13	3.16	0.03	
3.11	3.14	0.03	
2.89	2.98	0.09	

Table 3 2016 Flood Mark Comparisons

Surveyed Flood Mark Elevation (mAHD)	Simulated Water level (mAHD)	Difference (m)	Comments
3.12	2.99	-0.13	
3.11	2.93	-0.18	
3.09	2.99	-0.10	
2.99	2.99	0.00	
2.98	2.75	-0.23	
2.91	2.96	0.05	
2.82	2.75	-0.07	

Appendix F

Australian Rainfall & Runoff 2016 Assessment

AUSTRALIAN RAINFALL AND RUNOFF 2016

SENSITIVITY ASSESSMENT

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 and the commencement of the *'Murwillumbah CBD Levee & Drainage Study'*, a revised version of Australian Rainfall and Runoff has been released (Geoscience Australia, 2016) (referred to herein as ARR2016). Therefore, additional investigations were completed to confirm the impact that the revised hydrologic procedures may have on design flood behaviour in the vicinity of Murwillumbah.

It should be noted that this assessment only considered the 1% AEP flood.

Rainfall Intensity

Design rainfall intensities for the 1% AEP storm were downloaded from the Bureau of Meteorology's 2016 IFD webpage. This design rainfall information is presented in **Table 1** for storm duration of between 12 hours and 168 hours (i.e., 7 days). The design rainfall intensities were extracted at the centroid of the catchment upstream of Murwillumbah (Latitude = -28.388, Longitude = 153.288). The 1987 design rainfall intensities are also included in **Table 1** for comparison.

Table 1 1% AEP Design Rainfall Intensities for ARR 1987 and ARR 2016

Storm Duration	1% AEP Rainfall Intensity (mm/hr)		
	ARR 1987*	ARR 2016	Difference (%)
12 hours	30.0	36.6	22%
18 hours	24.2	30.3	25%
24 hours (1 day)	20.5	26.1	27%
36 hours (1.5 days)	16.2	20.6	27%
48 hours (2 days)	13.5	17.1	27%
72 hours (3 days)	10.4	12.9	24%
96 hours (4 days)	-	10.4	-
144 hours (6 days)	-	7.64	-
168 hours (7 days)	-	6.79	-

NOTE: * IFD data for storm durations greater than 72 hours was not available with ARR 1987

The comparison provided in **Table 1** indicates that the ARR2016 rainfall intensities are more than 20% higher than the equivalent ARR1987 rainfall intensities.

Areal Reduction Factors

ARR 2016 has also introduced revised areal reduction factors. The areal reduction factors recognise that there is unlikely to be a uniformly high rainfall intensity across all sections of large catchments. Although ARR 1987 did include areal reduction factors, this largely drew from overseas research.

The areal reduction factors parameter at the catchment centroid were downloaded from the ARR2016 data hub (a copy of the information downloaded from the data hub is included at the end of this document). The parameters were applied to the areal reduction equations provided in ARR2016 to develop the areal reduction factors provided in **Table 2**. These reduction factors were applied to the total rainfall depths listed in **Table 1** before application to the WBNM hydrologic model.

Table 2 ARR 2016 Areal Reduction Factors

Storm Duration	Areal Reduction Factor
12 hours	0.835
18 hours	0.886
24 hours (1 day)	0.903
36 hours (1.5 days)	0.912
48 hours (2 days)	0.918
72 hours (3 days)	0.927
96 hours (4 days)	0.938
144 hours (6 days)	0.945
168 hours (7 days)	0.949

By way of comparison, the *'Tweed Valley Flood Study'* (BMT WMB, 2009) applied a constant areal reductions factor of 0.95 for all design storms. Therefore, ARR2016 provides higher reduction factors, particularly for the shorter durations storms. However, when combined with the higher rainfall intensities, ARR2016 still provides a net increase in design rainfall intensities relative to ARR1987.

Temporal Patterns

One of the most significant differences between ARR2016 and ARR1987 is in the use of storm temporal patterns (i.e., the patterns describing the distribution of rainfall throughout the storm). ARR1987 used a single temporal pattern for each AEP/storm duration while ARR2016 uses a minimum of 10 temporal patterns for each AEP/storm duration.

The ARR2016 temporal patterns were downloaded from the ARR data hub. In accordance with ARR2016 for catchments with an area greater than 75 km^2, the "areal" temporal patterns rather than "point" temporal patterns were selected to describe the temporal variation in rainfall. The catchment upstream of Murwillumbah comprises an area of 860 km^2. Therefore, the temporal patterns for the 1000 km^2 catchment area were adopted.

A total of 10 separate temporal patterns were applied to the areal reduced rainfall depths for each storm duration. This provided a storm database comprising 100 different storms (i.e., 10 temporal patterns applied to each of the 10 different storm durations that were assessed).

It is noted that areal temporal patterns are not available in ARR 2016 for storm durations of less than 12 hours. Therefore, only storm durations of 12 hours or greater were analysed.

Rainfall Losses

ARR2016 also utilises a different approach for defining initial rainfall losses. The ARR1987 approach applies a constant initial rainfall loss for all storms (an initial rainfall loss of 0mm was adopted as part of the original flood study).

The ARR2016 approach employs an initial rainfall loss that varies accordingly to the storm duration. The ARR2016 initial rainfall losses are calculated by subtracting median pre-burst rainfall losses (which vary based on storm duration) from the overall storm loss for the catchment (an overall storm loss of 41mm is defined for the Tweed River catchment by ARR2016). The resulting "burst" initial rainfall losses are summarised in **Table 3**.

Table 3 Initial Rainfall Losses for the 1% AEP flood

Storm Duration	Storm Initial Loss (mm)	Median Pre-burst Depth (mm)	Burst Initial Loss (mm)
12 hours	41	165.5	0
18 hours		211.7	0
24 hours (1 day)		113.8	0
36 hours (1.5 days)		103.0	0
48 hours (2 days)		73.2	0
72 hours (3 days)		37.9	3.1
96 hours (4 days)		37.9	3.1
144 hours (6 days)		37.9	3.1
168 hours (7 days)		37.9	3.1

As shown in **Table 3**, initial rainfall losses of between 0 and 3.1mm were calculated. This does not differ significantly from the 0mm adopted as part of the original flood study.

Continuing loss rates are used in ARR2016 in a similar manner to how they were used in ARR1987. However, the values have changed. ARR2016 specifies a continuing loss rate of 2.8 mm/hour. A continuing loss rate of 2.5 m/hour was used as part of the previous ARR1987 assessment.

Design Simulations

Critical TP/Duration

The WBNM model that was developed as part of the original flood study was updated to include the database of 100 storms and the updated models were used to simulate each storm. The peak discharges from the full suite of temporal patterns were reviewed to determine the "critical" temporal pattern for each storm duration.

In accordance with guidance provided in ARR2016, the temporal pattern that generated the closest, but next highest peak discharge to the average discharge, was selected as the "critical" temporal pattern for each subcatchment.

The results of the ARR2016 simulations are presented in **Plates 1** and **2** as "box plots" for the Tweed and Rous Rivers at Murwillumbah. The box plots show:

- Average discharge for each storm duration (defined by the "✳");
- The first and third quartiles (defined by the green box), which illustrated the 25th percentile and 75th percentile discharge values;
- The highest and lowest discharge value (represented by the "T" attached to the end of the green box)
- The critical storm duration (representing the highest average flow value from all simulated durations) is highlighted in yellow

The 'box plots' indicate that the critical storm duration for both the Tweed and Rous Rivers at Murwillumbah is 12 hours. This is significantly lower than the 36-hour critical duration determined as part of the original flood study using ARR1987.

The analysis of the box plots determined that temporal pattern "35" was critical for the Tweed River and temporal pattern "37" was critical for the Rous River.

Plates 3 and **4** show the full suite of design flow hydrographs for the Tweed and Rous Rivers for the 10 different temporal patterns for the critical storm duration of 12 hours.

The box plots and hydrographs show some significant variations in peak flow values, particularly for the longer storm durations. For example, for the Tweed River at Murwillumbah, redistributing the same rainfall depths for the 12-hour storm can produce peak discharge estimates that vary between 5,010 m^3/s and 6,320 m^3/s.

A review of the temporal distributions of rainfall and the associated hydrographs indicates that a relatively uniform distribution of rainfall will generate the lowest peak discharge at Murwillumbah while an "end loaded" rainfall distribution (i.e., where most of the rain falls towards the end of the storm) generates the highest peak discharge at Murwillumbah.

This highlights that the temporal distribution of rainfall can have a significant impact on flood behaviour in the immediate vicinity of Murwillumbah.

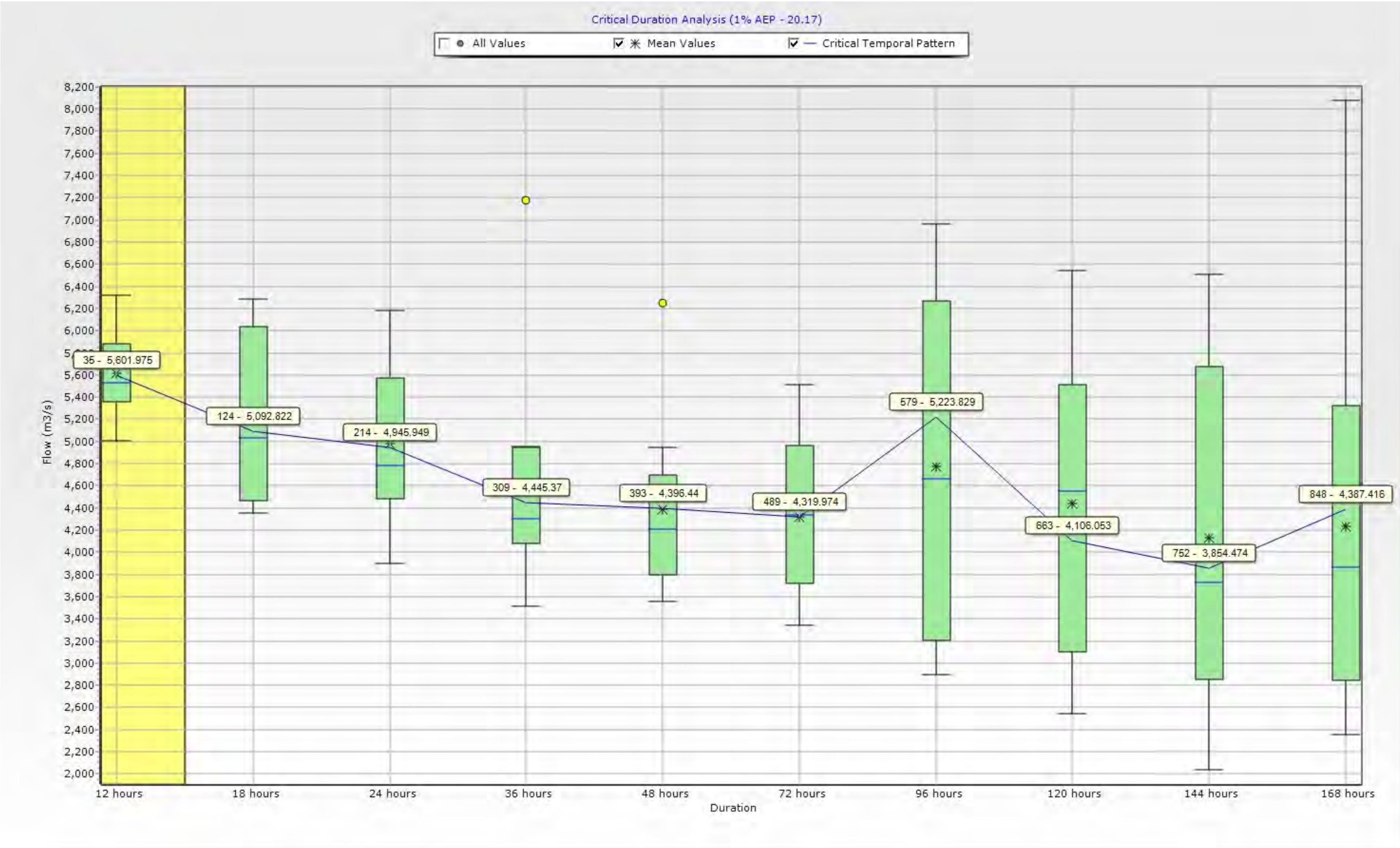


Plate 1 Box Plot for the Tweed River at Murwillumbah (subcatchment 20.17)

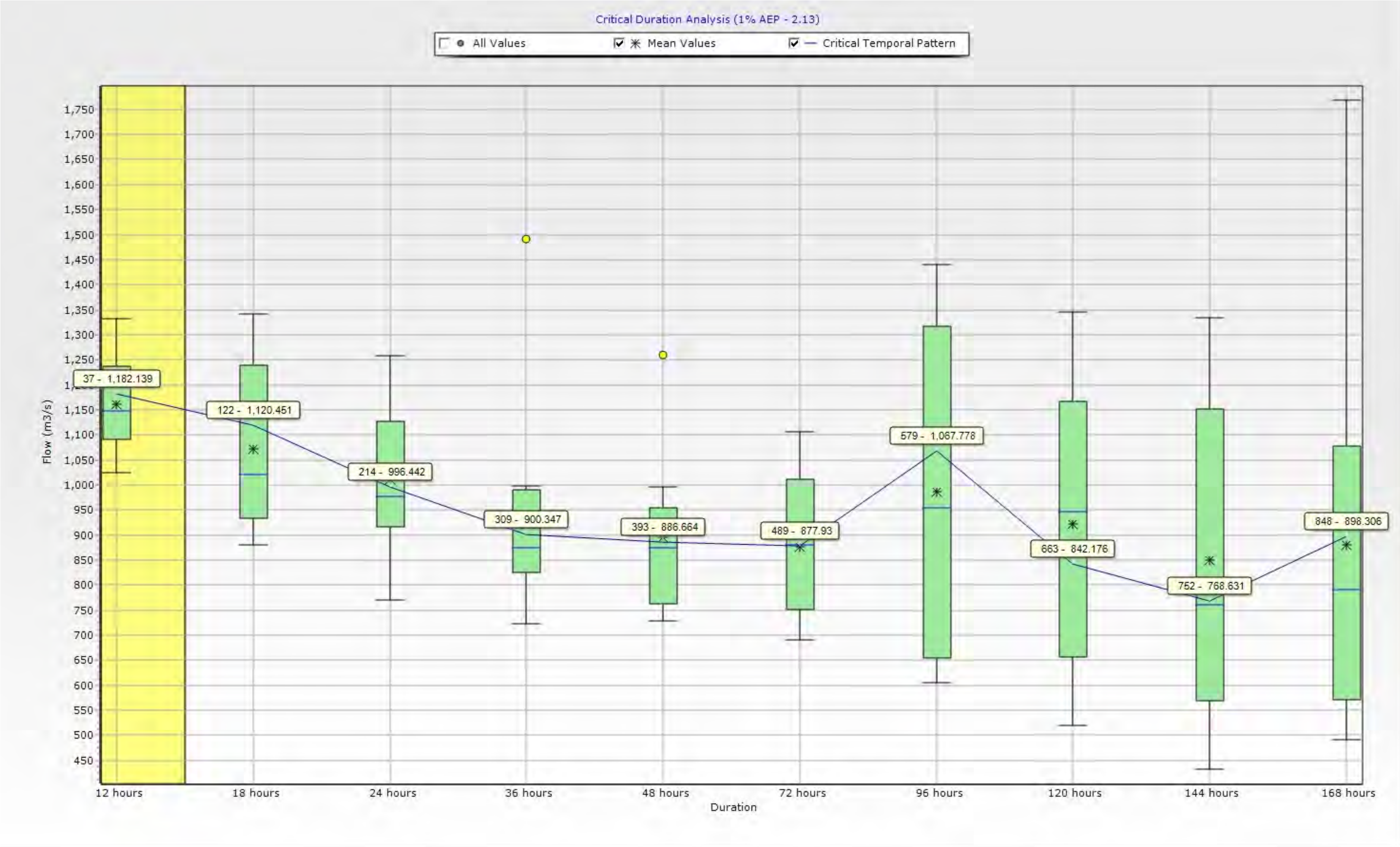


Plate 2 Box Plot for the Rous River at Murwillumbah (subcatchment 2.13

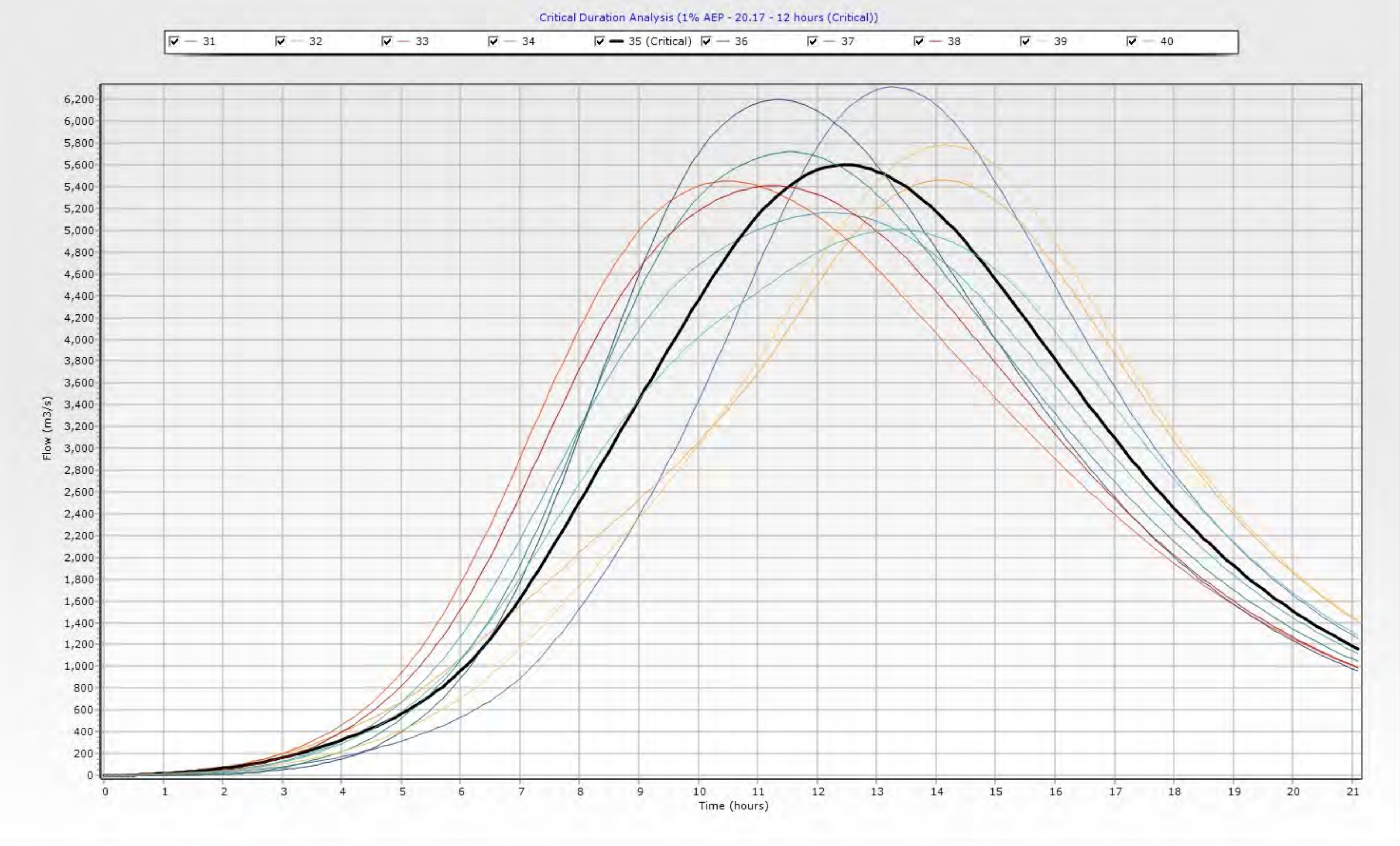


Plate 3 **Design Flow Hydrographs for the Tweed River at Murwillumbah (subcatchment 20.17)**

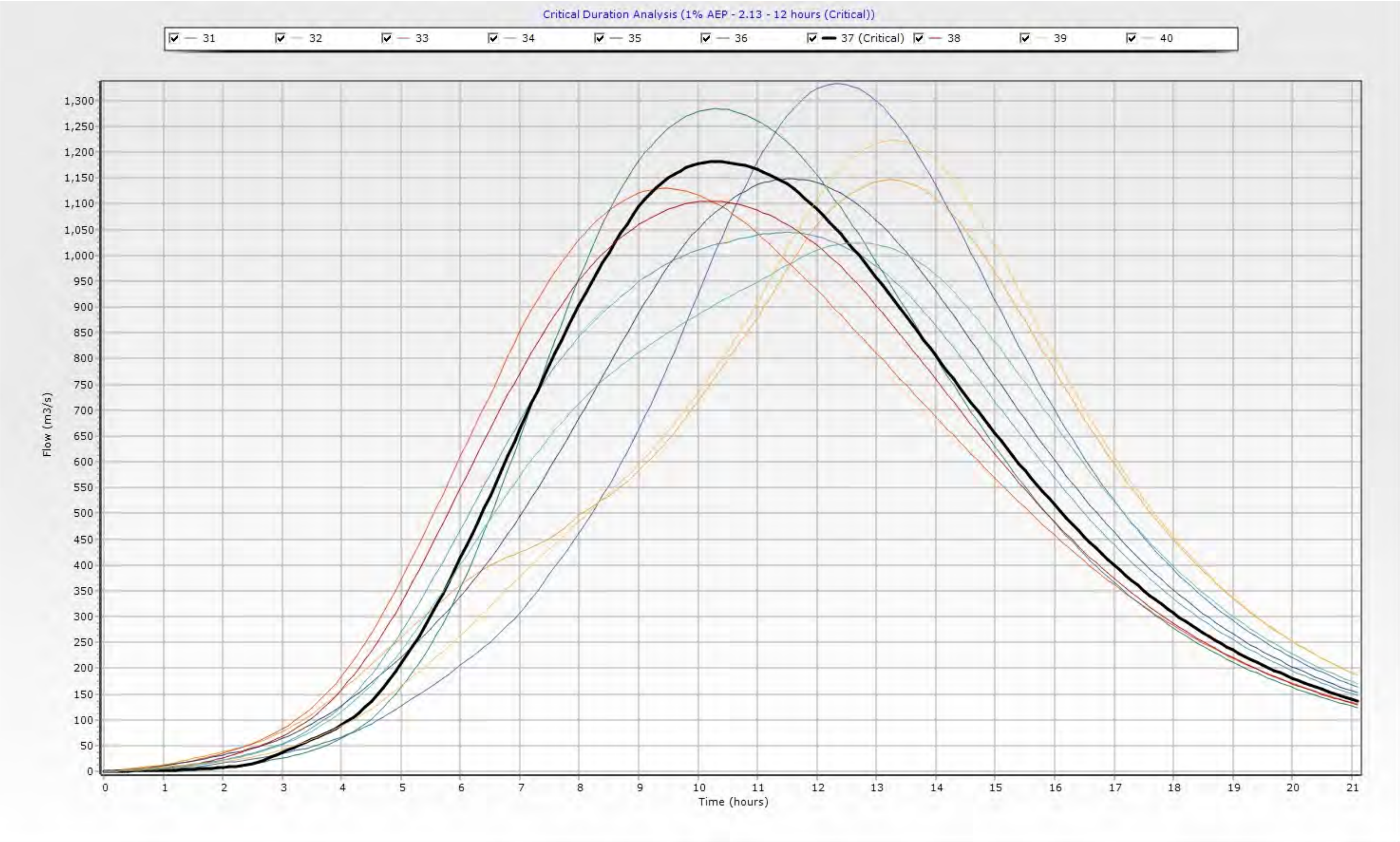


Plate 4 Design Flow Hydrographs for the Rous River at Murwillumbah (subcatchment 2.13)

Peak Discharges

It was noted that the ARR2016 analysis summarised in the previous sections adopted a uniform design rainfall across the catchment upstream of Murwillumbah. The original flood study completed with ARR1987 acknowledged that there is likely to be a spatial variation in design rainfall across the catchment. Therefore, intensity-frequency-duration values were extracted at five separate locations across the Tweed river catchment and were used to provided spatially varying design rainfall estimates.

To ensure consistency with the ARR 1987 hydrologic methodology that was applied as part of the "Tweed Valley Flood Study", the WBNM model was updated to include spatially varying ARR20916 design rainfall for the critical temporal patterns and durations described in the previous section. That is, 2016 IFD data was extracted at the same five locations for the 720-minute storm (this rainfall information is provided Error! Not a valid bookmark self-reference.).

Table 4 Spatially Varying 1% AEP, 12 Hour Design Rainfall Intensities for ARR 2016

Location	Rainfall Intensity (mm/hr)
Murwillumbah	29.2
Tomewin	38.3
Jerusalem Mt	32.8
Tyalgum	32.3
Fingal	29.8

The spatially varying ARR2016 rainfall was applied to the WBNM model in conjunction with temporal patterns 35 and 37. Peak discharges were extracted from the results of the ARR2016 modelling and are summarised in Error! Not a valid bookmark self-reference.. Error! Not a valid bookmark self-reference. also includes the original ARR1987 discharges.

Table 5 Comparison between ARR 1987 and ARR2016 1%AEP peak discharges at Murwillumbah

WBNM Subcatchment	Location Description	Peak 1% AEP Discharge (m^3/s)			
		ARR 1987	ARR 2016*		Difference
			Uniform Rainfall	Spatially Varying Rainfall	
20.17	Tweed River @ Murwillumbah	5,160	5,602	5,425	5.1%
2.13	Rous River @ Murwillumbah	1,170	1,182	1,175	0.4%

NOTE: *Peak discharge for the Tweed River are based on temporal pattern 35 and the peak Rous River discharge is based upon temporal pattern 37

A review of the peak discharges provided in

The spatially varying ARR2016 rainfall was applied to the WBNM model in conjunction with temporal patterns 35 and 37. Peak discharges were extracted from the results of the ARR2016 modelling and are summarised in Error! Not a valid bookmark self-reference.. Error! Not a valid bookmark self-reference. also includes the original ARR1987 discharges.

Table 5 shows that ARR2016 produces similar peak 1% AEP design discharges along the Rous River. However, peak ARR2016 1% AEP discharges along the Tweed River are predicted to be about 5% higher than the ARR1987 peak discharges.

Hydraulic Analysis

To quantify the impacts that the revised ARR2016 discharges may have on design flood behaviour in the vicinity of Murwillumbah, the TUFLOW model was updated to include the revised hydrology. The updated model was used to simulate the 1% AEP, 720-minute storm for temporal patterns 35 and 37.

The peak flood level results from both simulations were combined to form a final design flood level envelope. This peak flood level surface was subtracted from the 1% AEP ARR1987 flood level results surface to prepare flood level difference mapping. The flood level difference mapping shows the location and magnitude of changes in flood level/depths and inundation extent associated with the revised hydrologic procedures. The resulting difference mapping is presented in the attached **Figure F1**.

Figure F1 shows that ARR2016 is predicted to produce some significant differences in peak 1% AEP flood levels in the vicinity of Murwillumbah. More specifically, ARR2016 is generally predicted to produce <u>lower</u> 1% AEP flood levels across most of the area. This includes all of the Rous River and its floodplain as well as the Tweed River downstream of the Murwillumbah bridge (including East Murwillumbah. Therefore, although ARR2016 is predicted to produce a similar peak 1% AEP discharge for the Rous River and a higher peak 1% AEP discharge for the Tweed River, the reduced volume afforded by the 12-hour ARR2016 storm versus the 36-hour ARR1987 storm is predicted to produce lower flood levels. This indicates that it is the runoff volume rather than the peak discharges that is more critical across the Rous River and lower Tweed River floodplains.

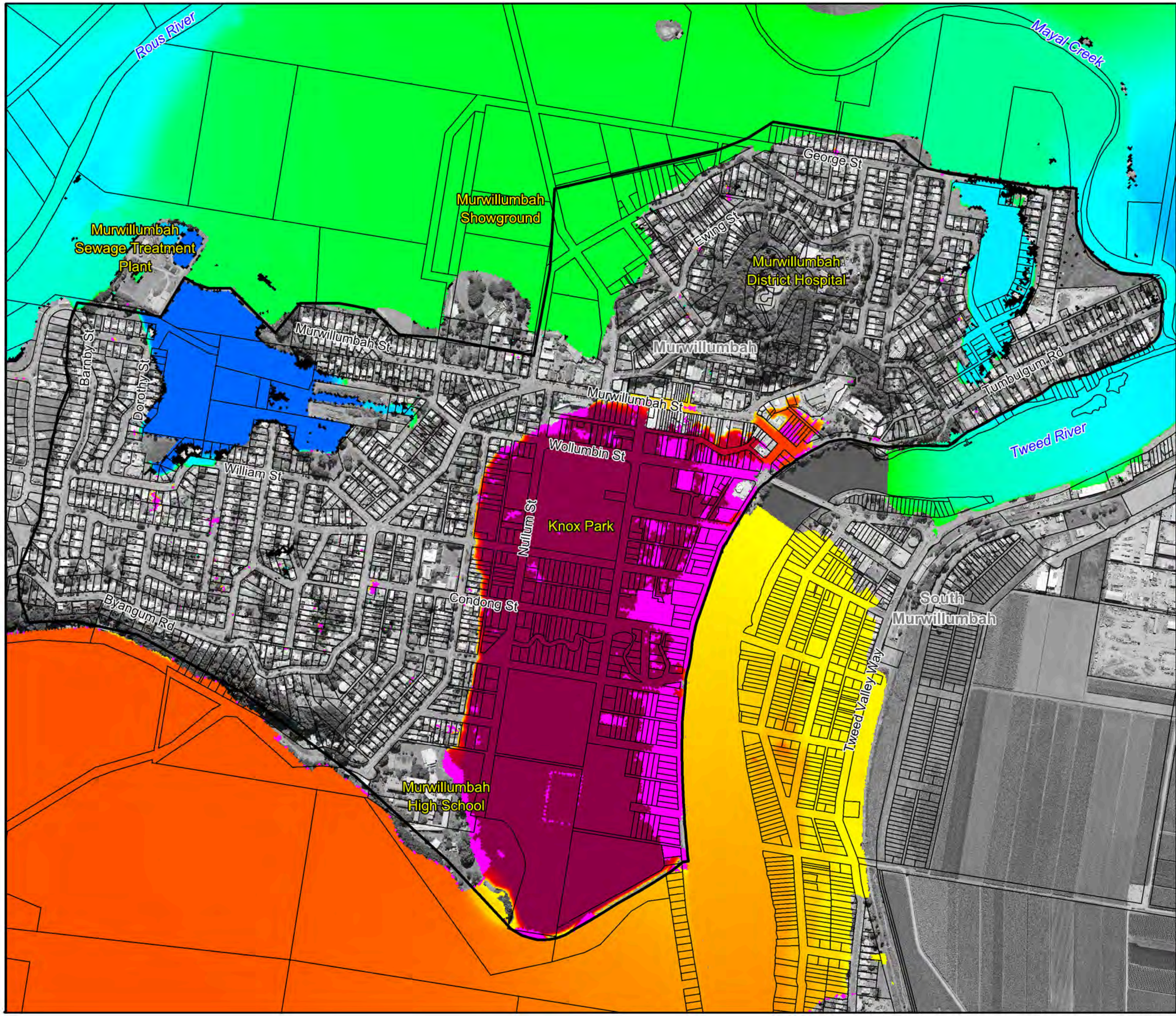
However, Figure F1 also shows that ARR2016 is predicted to generate higher peak 1% AEP flood level upstream of Murwillumbah. This includes a 0.2-0.3 metre increase immediately south of the Commercial Road earthen levee. This is predicted to significantly increase the quantify of flow across the Commercial Road levee and entering the Murwillumbah CBD during the 1% AEP floods. As a result, peak 1% AEP flood levels behind the levee are predicted to increase by over 1 metre relative to ARR1987.

Overall, ARR2016 is predicted to generate lower flood levels across areas protected by the East Murwillumbah and Dorothy Street levees and higher flood levels behind the Commercial Road levee.

Summary

The outcomes of this sensitivity assessment have determined that ARR2016 will produce some notable changes in 1% AEP flood levels when compared with ARR1987. Across most of the study area (e.g., East Murwillumbah and adjoining the Dorothy Street levee), ARR2016 generates lower peak flood level estimates relative to ARR1987. In these areas, it appears the volume of runoff has a greater impact on flood levels despite ARR2016 producing higher discharges. Accordingly, the use of the longer duration ARR1987 hydrographs is likely to provide conservative flood level estimates across these areas.

However, in the vicinity of the Commercial Road levee, ARR2016 is predicted to produce peak 1%AEP flood levels that are up to 0.3 metres higher than ARR1987. This is predicted to significantly increase 1% AEP flood levels in areas behind the Commercial Road levee. It also noted that the consideration of a 12-hour ARR2016 storm durations instead of a 36-hour



TWEED SHIRE COUNCIL

LEGEND

Water Level Difference (m)

- 1.00
- 0.50
- 0.25
- 0.10
- No Change
- -0.10
- -0.25
- -0.50
- -1.00
- Previously wet now dry
- Previously dry now wet

Notes:

Aerial photograph date: 2015

N
W E
S

0 0.25 0.5
Km

Figure F1:
Difference in Peak ARR 2016 and ARR 1987 1%AEP Flood Levels

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: F1 - 1AEP ARR Diff.wor

ARR1987 storm duration is likely to significantly reduce the available flood warning time. Accordingly, the use of ARR1987 hydrology may be underestimating the flood risk across the Murwillumbah CBD.

Australian Rainfall & Runoff Data Hub - Results

Input Data

Longitude	153.288
Latitude	-28.388
Selected Regions	
River Region	
ARF Parameters	
Temporal Patterns	
Areal Temporal Patterns	
Interim Climate Change Factors	

Region Information

Data Category	Region
River Region	Tweed River
ARF Parameters	East Coast North
Temporal Patterns	East Coast South

Data

River Region

division	South East Coast (NSW)
rivregnum	1
River Region	Tweed River

Layer Info

Time Accessed	14 September 2017 09:15AM
Version	2016_v1

ARF Parameters

Long Duration ARF

$$Areal\ reduction\ factor = Min\left\{1, \left[1 - a\left(Area^{b} - c\log_{10}Duration\right)Duration^{-d} + eArea^{f}Duration^{g}\left(0.3 + \log_{10}AEP\right) + h10^{iArea\frac{Duration}{1440}}\left(0.3 + \log_{10}AEP\right)\right]\right\}$$

Zone	East Coast North
a	0.327
b	0.241
c	0.448
d	0.36
e	0.00096
f	0.48
g	-0.21
h	0.012
i	-0.0013

Short Duration ARF

$$ARF = Min\left[1, 1 - 0.287\left(Area^{0.265} - 0.439\log_{10}(Duration)\right).Duration^{-0.36} + 2.26 \text{ x } 10^{-3} \text{ x } Area^{0.226}.Duration^{0.125}\left(0.3 + \log_{10}(AEP)\right) + 0.0141 \text{ x } Area^{0.213} \text{ x } 10^{-0.021\frac{(Duration-180)^{2}}{1440}}\left(0.3 + \log_{10}(AEP)\right)\right]$$

Layer Info

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Storm Losses

Note: Burst Loss = Storm Loss - Preburst

Note: These losses are only for rural use and are NOT FOR USE in urban areas

Storm Initial Losses (mm)	41.0
Storm Continuing Losses (mm/h)	2.8

Layer Info

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Version	2016_v1

Temporal Patterns

code	ECsouth
Label	East Coast South

Layer Info

Time Accessed	14 September 2017 09:15AM
Version	2016_v2

Areal Temporal Patterns

code	ECsouth
arealabel	East Coast South

Layer Info

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Version	2016_v2

BOM IFD Depths

Click here to obtain the IFD depths for catchment centroid from the BoM website

Layer Info

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Median Preburst Depths and Ratios

Values are of the format depth (ratio) with depth in mm

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	2.0 (0.051)	5.3 (0.1)	7.5 (0.12)	9.6 (0.132)	10.4 (0.119)	10.9 (0.111)
90 (1.5)	4.3 (0.093)	11.9 (0.186)	16.9 (0.22)	21.7 (0.242)	15.8 (0.145)	11.4 (0.091)
120 (2.0)	6.2 (0.119)	15.6 (0.212)	21.7 (0.244)	27.6 (0.263)	22.9 (0.178)	19.4 (0.131)
180 (3.0)	17.8 (0.282)	30.2 (0.333)	38.5 (0.346)	46.3 (0.349)	68.3 (0.418)	84.8 (0.448)
360 (6.0)	25.7 (0.283)	50.7 (0.376)	67.2 (0.401)	83.1 (0.411)	113.1 (0.451)	135.5 (0.466)
720 (12.0)	25.6 (0.19)	53.2 (0.26)	71.4 (0.279)	88.9 (0.287)	132.7 (0.348)	165.5 (0.377)
1080 (18.0)	18.9 (0.111)	45.4 (0.175)	63.0 (0.194)	79.8 (0.204)	155.2 (0.325)	211.7 (0.388)
1440 (24.0)	11.0 (0.055)	38.5 (0.127)	56.6 (0.149)	74.1 (0.162)	96.8 (0.175)	113.8 (0.182)
2160 (36.0)	12.0 (0.049)	38.9 (0.105)	56.7 (0.123)	73.8 (0.134)	90.7 (0.137)	103.3 (0.139)
2880 (48.0)	2.9 (0.01)	29.5 (0.07)	47.0 (0.091)	63.9 (0.103)	69.2 (0.094)	73.2 (0.089)
4320 (72.0)	0.0 (0.0)	7.8 (0.016)	13.0 (0.022)	18.0 (0.026)	29.4 (0.035)	37.9 (0.041)

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10% Preburst Depths

min (h)\AEP(%)	50	20	10	5	2	1
60 (1.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
90 (1.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
120 (2.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
180 (3.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.001)	0.1 (0.001)	0.0 (0.0)	0.0 (0.0)
360 (6.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	3.4 (0.014)	5.9 (0.02)
720 (12.0)	0.0 (0.0)	1.4 (0.007)	2.3 (0.009)	3.2 (0.01)	26.1 (0.068)	43.2 (0.098)
1080 (18.0)	0.0 (0.0)	2.2 (0.009)	3.7 (0.011)	5.1 (0.013)	46.2 (0.097)	76.9 (0.141)
1440 (24.0)	0.0 (0.0)	0.4 (0.001)	0.6 (0.002)	0.9 (0.002)	25.1 (0.046)	43.3 (0.069)
2160 (36.0)	0.0 (0.0)	0.4 (0.001)	0.6 (0.001)	0.8 (0.002)	13.1 (0.02)	22.4 (0.03)
2880 (48.0)	0.0 (0.0)	1.0 (0.002)	1.7 (0.003)	2.3 (0.004)	2.2 (0.003)	2.1 (0.003)
4320 (72.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Layer Info

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25% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	0.2 (0.004)	0.3 (0.006)	0.4 (0.006)	0.5 (0.007)	0.4 (0.005)	0.4 (0.004)
90 (1.5)	0.0 (0.0)	1.0 (0.016)	1.7 (0.022)	2.3 (0.026)	1.3 (0.012)	0.5 (0.004)
120 (2.0)	0.0 (0.0)	1.1 (0.016)	1.9 (0.021)	2.6 (0.025)	1.9 (0.015)	1.3 (0.009)
180 (3.0)	0.6 (0.009)	2.4 (0.026)	3.6 (0.032)	4.7 (0.036)	5.4 (0.033)	5.9 (0.031)
360 (6.0)	2.1 (0.023)	4.7 (0.035)	6.4 (0.038)	8.1 (0.04)	39.4 (0.157)	62.9 (0.216)
720 (12.0)	5.7 (0.043)	22.1 (0.108)	32.9 (0.128)	43.3 (0.14)	65.2 (0.171)	81.6 (0.186)
1080 (18.0)	1.3 (0.008)	8.6 (0.033)	13.4 (0.041)	18.0 (0.046)	76.3 (0.16)	120.1 (0.22)
1440 (24.0)	0.3 (0.002)	12.7 (0.042)	20.9 (0.055)	28.8 (0.063)	44.1 (0.08)	55.6 (0.089)
2160 (36.0)	0.0 (0.0)	9.8 (0.026)	16.3 (0.035)	22.5 (0.041)	27.0 (0.041)	30.3 (0.041)
2880 (48.0)	0.0 (0.0)	4.6 (0.011)	7.7 (0.015)	10.7 (0.017)	10.6 (0.014)	10.6 (0.013)
4320 (72.0)	0.0 (0.0)	0.1 (0.0)	0.2 (0.0)	0.2 (0.0)	0.2 (0.0)	0.2 (0.0)

Layer Info

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75% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	29.5 (0.756)	38.6 (0.729)	44.6 (0.71)	50.4 (0.691)	47.4 (0.545)	45.1 (0.459)
90 (1.5)	29.2 (0.634)	63.1 (0.988)	85.6 (1.115)	107.1 (1.191)	108.6 (0.998)	109.8 (0.884)
120 (2.0)	52.7 (1.008)	81.5 (1.109)	100.6 (1.13)	118.8 (1.131)	145.8 (1.136)	166.1 (1.126)
180 (3.0)	64.9 (1.026)	102.2 (1.126)	127.0 (1.142)	150.7 (1.136)	191.5 (1.171)	222.1 (1.174)
360 (6.0)	76.3 (0.84)	124.8 (0.926)	157.0 (0.936)	187.8 (0.928)	234.8 (0.935)	269.9 (0.928)
720 (12.0)	58.6 (0.434)	123.9 (0.606)	167.1 (0.653)	208.6 (0.673)	254.8 (0.668)	289.5 (0.659)
1080 (18.0)	45.8 (0.269)	100.9 (0.389)	137.3 (0.423)	172.3 (0.44)	356.1 (0.745)	493.8 (0.906)
1440 (24.0)	47.7 (0.24)	101.0 (0.333)	136.2 (0.359)	170.0 (0.372)	319.2 (0.578)	430.9 (0.688)
2160 (36.0)	55.6 (0.228)	97.7 (0.264)	125.6 (0.273)	152.4 (0.276)	219.0 (0.332)	268.9 (0.362)
2880 (48.0)	39.0 (0.141)	98.0 (0.234)	137.1 (0.265)	174.6 (0.283)	200.6 (0.273)	220.0 (0.267)
4320 (72.0)	18.0 (0.056)	44.4 (0.092)	61.9 (0.105)	78.7 (0.112)	134.1 (0.161)	175.7 (0.189)

Layer Info

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90% Preburst Depths

min (h)\AEP (%)	50	20	10	5	2	1
60 (1.0)	117.5 (3.009)	130.8 (2.469)	139.6 (2.22)	148.1 (2.031)	191.8 (2.203)	224.5 (2.282)
90 (1.5)	147.9 (3.204)	173.0 (2.707)	189.6 (2.471)	205.5 (2.286)	247.0 (2.27)	278.1 (2.238)
120 (2.0)	133.7 (2.555)	186.9 (2.543)	222.2 (2.496)	256.0 (2.436)	263.6 (2.053)	269.2 (1.825)
180 (3.0)	124.7 (1.973)	201.4 (2.218)	252.2 (2.267)	300.9 (2.269)	360.3 (2.203)	404.8 (2.14)
360 (6.0)	193.7 (2.133)	259.8 (1.928)	303.5 (1.811)	345.5 (1.707)	551.0 (2.196)	705.1 (2.423)
720 (12.0)	122.5 (0.908)	226.4 (1.107)	295.1 (1.152)	361.1 (1.164)	483.2 (1.266)	574.8 (1.309)
1080 (18.0)	143.1 (0.842)	231.2 (0.892)	289.5 (0.893)	345.5 (0.881)	496.8 (1.04)	610.2 (1.12)
1440 (24.0)	133.9 (0.673)	212.8 (0.701)	265.0 (0.699)	315.1 (0.69)	396.1 (0.718)	456.9 (0.73)
2160 (36.0)	108.1 (0.443)	181.9 (0.491)	230.7 (0.501)	277.6 (0.503)	374.3 (0.567)	446.8 (0.602)
2880 (48.0)	89.2 (0.323)	171.0 (0.409)	225.3 (0.435)	277.3 (0.449)	329.5 (0.448)	368.7 (0.448)
4320 (72.0)	65.1 (0.204)	107.2 (0.223)	135.1 (0.228)	161.8 (0.23)	195.9 (0.235)	221.4 (0.238)

Layer Info

Time Accessed	14 September 2017 09:15AM
Version	2016_v2

Interim Climate Change Factors

Values are of the format temperature increase in degrees Celcius (% increase in rainfall)

	RCP 4.5	RCP6	**RCP 8.5**
2030	**0.892 (4.5%)**	0.775 (3.9%)	**0.979 (4.9%)**
2040	**1.121 (5.6%)**	1.002 (5.0%)	**1.351 (6.8%)**
2050	**1.334 (6.7%)**	1.28 (6.4%)	**1.765 (8.8%)**
2060	**1.522 (7.6%)**	1.527 (7.6%)	**2.23 (11.2%)**
2070	**1.659 (8.3%)**	1.745 (8.7%)	**2.741 (13.7%)**
2080	**1.78 (8.9%)**	1.999 (10.0%)	**3.249 (16.2%)**
2090	**1.825 (9.1%)**	2.271 (11.4%)	**3.727 (18.6%)**

Layer Info

Time Accessed	14 September 2017 09:15AM
Version	2016_v1
Note	ARR recommends the use of RCP4.5 and RCP 8.5 values

APPENDIX G

FLOOD DAMAGES ASSESSMENT

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B1 Flood Damage Calculations

1.1 Introduction

In an effort to quantify the potential economic impact that flooding has on the Murwillumbah CBD study area, a flood damage assessment was completed. The following sections summarise the methodology employed to quantify flood damage costs as well as the results of the damage assessment

1.2 Background

The damage costs associated with inundation can be broken down into a number of categories, as shown in **Plate 1**. However, broadly speaking, damage costs fall under two major categories;

- tangible damages; and
- intangible damages.

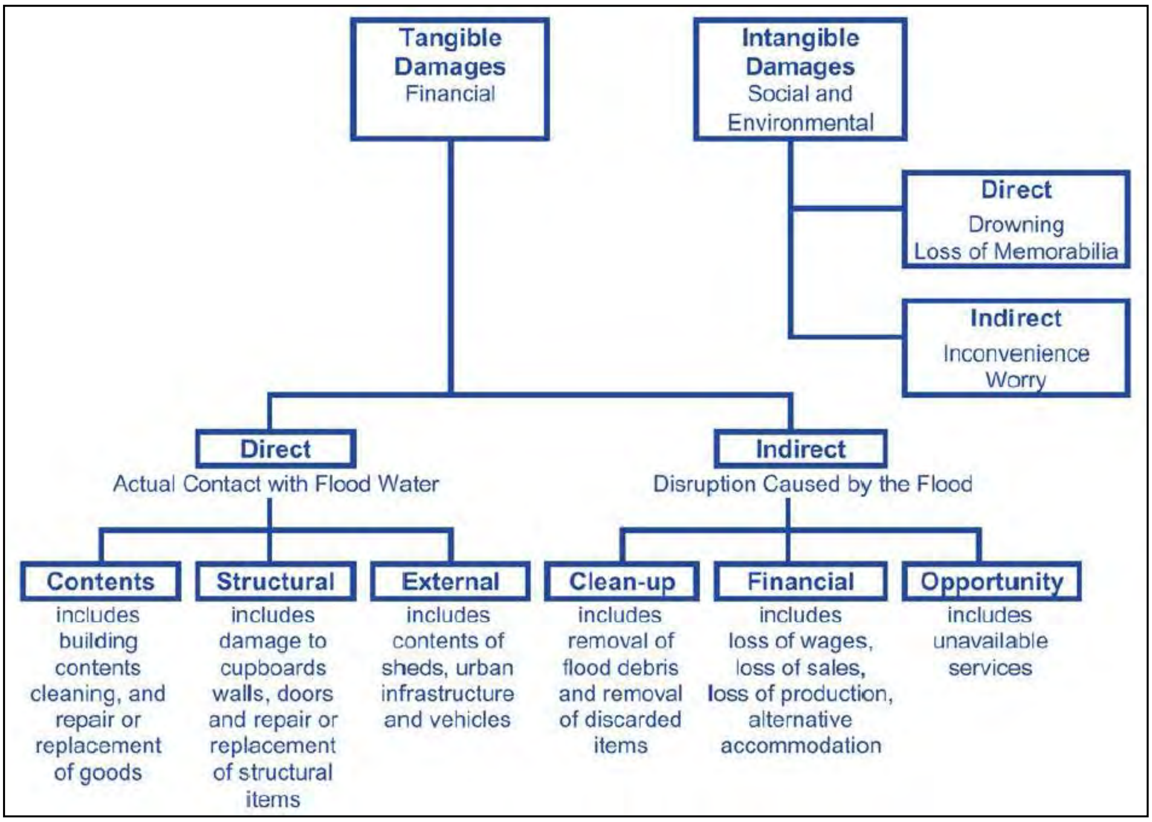


Plate 1 Flood Damage Categories (NSW Government, 2005)

Tangible damages are those which can be quantified in monetary terms (e.g., cost to replace household items damaged by waters). Intangible damages cannot be as readily quantified in monetary terms and include items such as inconvenience and emotional stress.

Tangible damages can be further broken down into direct and indirect damage costs. Direct costs are associated with water coming into direct contact with buildings and contents. Indirect flood damage costs are costs incurred outside of the specific inundation event. Indirect damage costs can include clean-up costs, loss of trade (for commercial/industrial properties) and/or alternate accommodation costs while clean-up/repairs are undertaken.

Due to the difficulty associated with assigning monetary values to intangible damages, only tangible damages were considered as part of this study. Further information on how tangible damages costs were estimated is presented in the following sections.

1.3 Flood Damage Calculations

1.3.1 Property Database

In order to quantify flood damages, it is necessary to build a property database for all residential, commercial and industrial properties in the study area. A property database that was previous prepared as part of the *'Tweed Valley Floodplain Risk Management Study'* (BMT WBM, 2014) was also used as part of the current assessment. The property database included the following information:

- Building floor level;
- Property type (i.e., residential, commercial or industrial);
- Building Construction Type (Brick, Weather Board, etc);
- Residential building type (i.e., two story, single level high set, single level low set);
- Commercial/Industrial building type (eg: Office, Hardware, service station)
- Building size;

Once this property database is compiled, it can be compared against design flood level information to determine the depth of above floor inundation during each design flood. The over floor flooding depth can, in turn, be used with flood damage curves to estimate the damage costs for the specific property type. Further details on how the flood damage curves were developed is provided below.

1.3.2 Residential Properties

The NSW Office of Environment and Heritage (OEH) has prepared a spreadsheet that provides a standardised approach for deriving damage curves for residential properties (version 3.00, October 2007). The damage curves describe flood damage costs relative to the depth of flooding above floor level.

The spreadsheet requires a range of parameters to be defined to enable a meaningful damage estimate to be derived. The parameters that were adopted for the current study are provided on the following page.

SITE SPECIFIC INFORMATION FOR RESIDENTIAL DAMAGE CURVE DEVELOPMENT

Version 3.00 October 2007

PROJECT	DETAILS	DATE	JOB No.
Smithfield West	**Residential Damages (120m2)**	**18/02/2015**	**xx**

BUILDINGS

Regional Cost Variation Factor	1.03	*From Rawlinsons*					
Post late 2001 adjustments	1.75	*Changes in AWE see AWE Stats Worksheet*					
Post Flood Inflation Factor	1.00	*1.0*	*to*	*1.5*			
Multiply overall structural costs by this factor		*Judgement to be used. Some suggestions below*					
	Regional City			*Regional Town*			
		Houses Affected	*Factor*		*Houses Affected*	*Factor*	
Small scale impact	*<*	*50*	*1.00*	*<*	*10*	*1.00*	
Medium scale impacts in Regional City		*100*	*1.20*		*30*	*1.30*	
Large scale impacts in Regional City	*>*	*150*	*1.40*	*>*	*50*	*1.50*	
Typical Duration of Immersion	0.5	hours					
Building Damage Repair Limitation Factor	0.85	*due to no insurance*		*short duration*		*long duration*	
		Suggested range		*0.85*	*to*	*1.00*	
Typical House Size	110	m^2		*240 m^2 is Base*			
Building Size Adjustment	0.5						
Total Building Adjustment Factor	**0.70**						

CONTENTS

Average Contents Relevant to Site	$ 29,548		*Base for 240 m^2 house*		*$*	*60,000*	
Post late 2001 adjustments	1.75	*From above*					
Contents Damage Repair Limitation Factor	0.75	*due to no insurance*		*short duration*		*long duration*	
Sub-Total Adjustment Factor	1.31	*Suggested range*		*0.75*	*to*	*0.90*	
Level of Flood Awareness	low	*low or high only. Low default unless otherwise justifiable.*					
Effective Warning Time	0	hour					
Interpolated DRF adjustment (Awareness/Time)	1.00	IDRF = Interpolated Damage Reduction Factor					
Typical Table/Bench Height (TTBH)	0.90	*0.9m is typical height. If typical is 2 storey house use 2.6m.*					
Total Contents Adjustment Factor AFD <= TTBH	**1.31**	AFD = Above Floor Depth					
Total Contents Adjustment Factor AFD > TTBH	**1.31**						

Most recent advice from Victorian Rapid Assessment Method

Low level of awareness is expected norm (long term average) any deviation needs to be justified.

Basic contents damages are based upon a DRF of	*0.9*				
Effective Warning time (hours)	***0***	***3***	***6***	***12***	***24***
RAM Average IDRF Inexperienced (Low awareness)	*0.90*	*0.80*	*0.80*	*0.80*	*0.70*
DRF (ARF/0.9)	*1.00*	*0.89*	*0.89*	*0.89*	*0.78*
RAM AIDF Experienced (High awareness)	*0.80*	*0.80*	*0.60*	*0.40*	*0.40*
DRF (ARF/0.9)	*0.89*	*0.89*	*0.67*	*0.44*	*0.44*
Site Specific DRF (DRF/0.9) for Awareness level for iteration	*1.00*	*0.89*	*0.89*	*0.89*	*0.78*
Effective Warning time (hours)	*0*	*3*	*0*		
Site Specific iterations	*1.00*	*0.89*	*1.00*		

ADDITIONAL FACTORS

Post late 2001 adjustments	1.75	*From above*
External Damage	$ 6,700	*$6,700 recommended without justification*
Clean Up Costs	$ -	*$4,000 recommended without justification*
Likely Time in Alternate Accommodation	0	weeks
Additional accommodation costs /Loss of Rent	$ -	*$220 per week recommended without justification*

TWO STOREY HOUSE BUILDING & CONTENTS FACTORS

Up to Second Floor Level, less than	2.6	m	70%	Single Storey Slab on Ground
From Second Storey up, greater than	2.6	m	110%	Single Storey Slab on Ground

Base Curves

AFD = Above Floor Depth

Single Storey Slab/Low Set	13164	+	4871		x	AFD in metres
Structure with GST	AFD	greater than	0.0	m		
Validity Limits	AFD	less than or equal to			6	m
Single Storey High Set	16586	+	7454		x	AFD
Structure with GST	AFD	greater than	-2.40	m		
Validity Limits	AFD	less than or equal to			6	m
Contents	20000	+	20000		x	AFD
Contents with GST	AFD	greater than			0	
Validity Limits	AFD	less than or equal to			2	

It was noted that the resulting depth-damage curves incorporate a damage allowance for 'negative' depths. This is intended to reflect that property damage can be incurred when the water level is below floor level (e.g., damage to fences, garages, sheds). The damage curves for 'single storey low set' and 'two storey' properties commence at -0.2 metres. This was considered to be too small for the study area due to the steep terrain across most of the study area. Therefore, this value was increases to -0.5 metres.

The default 'single storey high set' damage curves commence at -5 metres. In order to verify the suitability of this value, single storey high set building floor levels within the PMF extent were compared against the minimum ground elevation within each lot (i.e., the minimum elevation within each lot at which inundation will first occur and, therefore, where damage is likely to commence). This determined that the median difference between the building floor level and minimum ground level within the corresponding lot was 2.4 metres. Accordingly, the 'single-storey high set' damage curves were adjusted so that damage commenced only when the flood level was less than 2.4 metres below the floor level.

The building floor area serves as another residential damage curve input. The floor area of all residential buildings within the study was reviewed and it was determined that the median floor area was 110 m^2.

The resulting residential depth-damage curves are included on the following page. The residential depth-damage curves include allowances for both direct and indirect cost components.

1.3.3 Commercial and Industrial Properties

Depth-damage curves that were used as part of *"Ballina Floodplain Risk Management Study"* (BMT WBM, 2012) were extracted and used to define commercial and industrial flood damages for the study area (these damages curves were also used in the *'Tweed Valley Floodplain Risk Management Study'*). However, the depth-damage curves were updated to 2017 dollars using Consumer Price Index (CPI) values published by the Australian Bureau of Statistics (ABS).

As noted in **Section 1.3.1**, each commercial and industrial property was classified according to the value of the contents (i.e., low or high damage potential). This is intended to reflect the fact that the damage incurred across commercial and industrial properties is likely to be heavily influenced by the value of its contents. **Table 1** provides a summary of common commercial and industrial property types and the associated contents.

The commercial and industrial properties were also broken down based on the size of the building into three categories; small (<186m^2), Medium (186 – 650m^2) or large (>650m^2). This is intended to reflect that the flood damages costs are also related to the size of the property. This size was combined with the contents value to assign the appropriate depth-damage curve for the individual property. The adopted commercial/Industrial depth-damage curves are presented on the following page.

Floodplain Specific Damage Curves for Individual Residences

Steps in Curve 0.1 m

	Single Storey High Set	Single Storey Slab/Low Set	2 Storey Houses
Type	**1**	**2**	**3**
AFD from Modelling	**Damage**	**Damage**	**Damage**
-5.00	$0	$0	$0
-2.40	$11,725	$0	$0
-2.30	$11,857	$0	$0
-2.20	$12,380	$0	$0
-2.10	$12,903	$0	$0
-2.00	$13,427	$0	$0
-1.90	$13,950	$0	$0
-1.80	$14,474	$0	$0
-1.70	$14,997	$0	$0
-1.60	$15,520	$0	$0
-1.50	$16,044	$0	$0
-1.40	$16,567	$0	$0
-1.30	$17,091	$0	$0
-1.20	$17,614	$0	$0
-1.10	$18,137	$0	$0
-1.00	$18,661	$0	$0
-0.90	$19,184	$0	$0
-0.80	$19,708	$0	$0
-0.70	$20,231	$0	$0
-0.60	$20,754	$0	$0
-0.50	$21,278	$11,725	$11,725
-0.40	$21,801	$11,725	$11,725
-0.30	$22,325	$11,725	$11,725
-0.20	$22,848	$11,725	$11,725
-0.10	$23,372	$11,725	$11,725
0.00	$36,822	$20,969	$18,196
0.10	$38,638	$35,531	$28,389
0.20	$40,454	$37,166	$29,533
0.30	$42,271	$38,800	$30,678
0.40	$44,087	$40,435	$31,822
0.50	$45,903	$42,070	$32,966
0.60	$47,719	$43,705	$34,111
0.70	$49,535	$45,339	$35,255
0.80	$51,351	$46,974	$36,399
0.90	$53,167	$48,609	$37,544
1.00	$54,984	$50,244	$38,688
1.10	$56,800	$51,879	$39,832
1.20	$58,616	$53,513	$40,977
1.30	$60,432	$55,148	$42,121
1.40	$62,248	$56,783	$43,265
1.50	$64,064	$58,418	$44,410
1.60	$65,880	$60,052	$45,554
1.70	$67,696	$61,687	$46,698
1.80	$69,513	$63,322	$47,843
1.90	$71,329	$64,957	$48,987
2.00	$73,145	$66,591	$50,131
2.10	$73,668	$66,933	$50,371
3.50	$80,996	$71,722	$77,722
4.00	$83,613	$73,432	$79,603
4.50	$86,230	$75,142	$81,484
5.00	$88,847	$76,853	$83,365

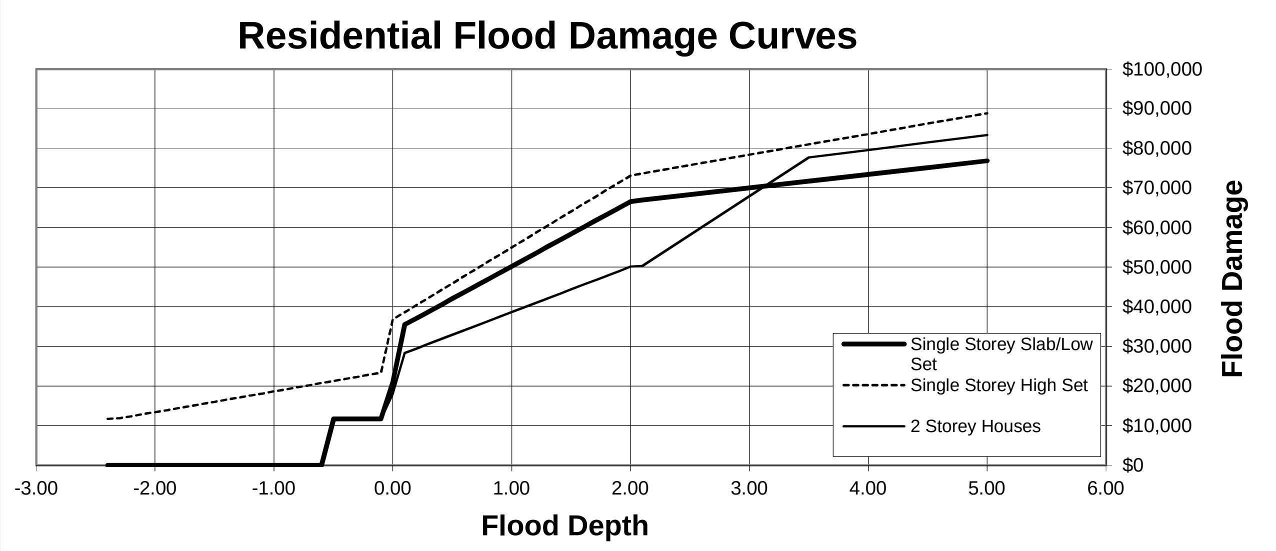


Table 1 Content Value Categories for Commercial and Industrial Property Types

	Low Value Contents	High Value Contents
Commercial	Florists	Chemists
	Garden Centres	Music instruments
	Café/Take away food	Printing
	Restaurants	Electric Goods
	Sports pavilions	Men's& Women's Clothing
	Consulting rooms	Bottle shops
	Doctors' surgeries	Cameras
	offices	Pharmaceuticals
	schools	Electronics
	churches	
	Post Offices	
	Food, retail outlets	
	Butchers	
	Bakeries	
	Newsagents	
	Pubs	
	Libraries	
	Clubs	
Industrial	Hardware	
	Service Stations	
	Vehicle sales	

An allowance of 55% of the direct flood damages was included to account for indirect damage costs to commercial and industrial properties, such as clean-up costs and loss of income while clean-up occurs. This was also adopted as part of the Ballina and Tweed Valley floodplain risk management studies.

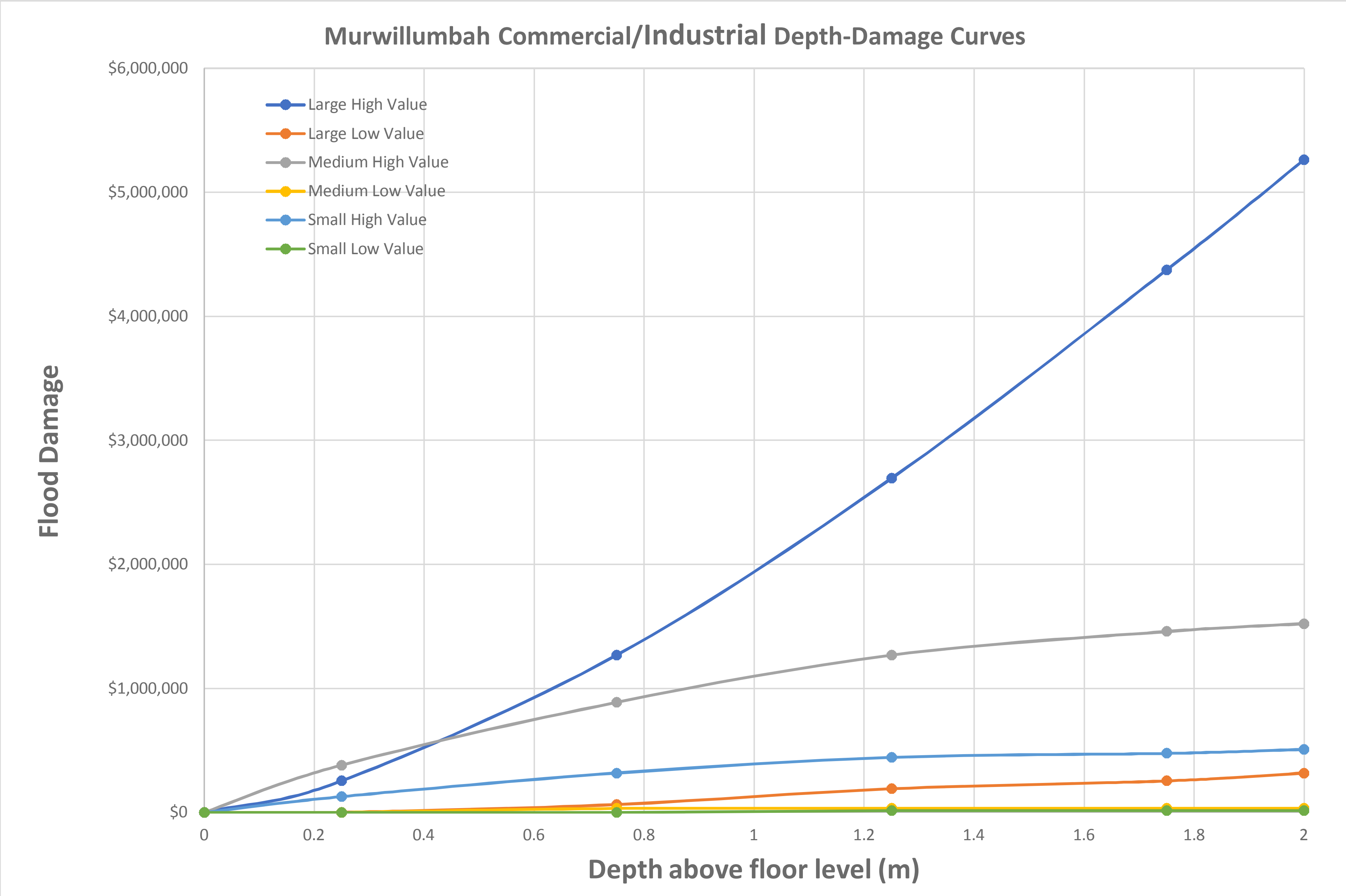
1.3.4 Infrastructure Damage

Infrastructure damage refers to damage to public infrastructure and utilities such as roads, water supply, sewerage, gas, electricity and telephone. For this study, the enfrastructure damage was estimated at 15% of total direct damages. This value was also adopted by part of Ballina and Tweed Valley floodplain risk management studies.

1.4 Summary of Inundation Costs

1.4.1 Damage Costs

Flood damages were calculated using the flood level surfaces for each design flood in conjunction with the appropriate depth-damage curves and floor levels for each building. The individual property damage estimates were subsequently summed with calculated infrastructure damage to calculate the total flood damages for each design event.



Murwillumbah Commercial/Industrial Depth-Damage Curves
$6,000,000
$5,000,000
$4,000,000
$3,000,000
$2,000,000
$1,000,000
$0
Flood Damage
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Depth above floor level (m)
Large High Value
Large Low Value
Medium High Value
Medium Low Value
Small High Value
Small Low Value

The total number of buildings incurring above floor inundation during each design flood are presented in **Table 2**. The total damage costs for each design flood is summarised in **Table 3**.

In general, commercial and industrial damage costs dominate for floods up to and including the 1% AEP. However, roughly an equal number of commercial/industrial properties and residential properties are impacted during the 0.2% AEP flood.

1.4.2 Average Annual Damages

The total flood damages for each flood event were plotted on a chart against the probability of each flood occurring (i.e., AEP). The chart was then used as the basis for calculating the average annual damages (AAD) for the study area for existing conditions. The AAD provides an estimate of the average annual cost of inundation across the study area over an extended timeframe.

The AAD for the study area, for existing conditions, was calculated to be $1.11 million.

Table 2 Number of Properties with Above Floor Inundation

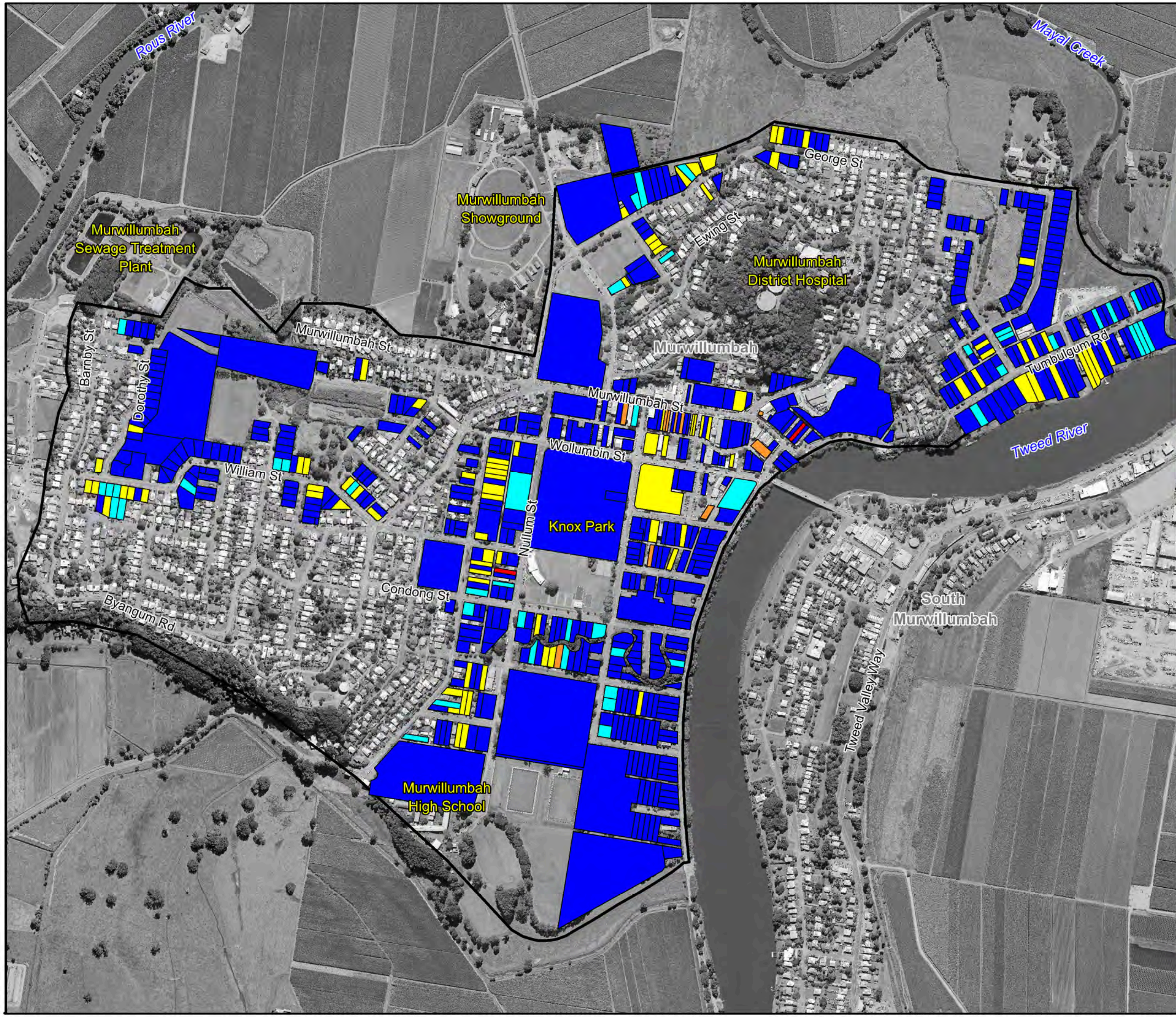
Flood Event	Number of buildings with Above Flood Inundation		
	Residential	Commercial/ Industrial	Total Number
20% AEP	1	11	12
5% AEP	1	21	22
1% AEP	2	30	32
0.2% AEP	58	59	117

Table 3 Flood Damage Costs

Flood Event	Flood Damages ($ millions)		
	Residential	Commercial/ Industrial	Total Damages
20% AEP	1.96	0.23	2.19
5% AEP	2.38	0.38	2.76
1% AEP	3.50	1.15	4.65
0.2% AEP	15.95	43.35	59.31

1.5 Limitations of Inundation Costs

The damage costs presented in this document are based on the best information that was available at the time this report was prepared. However, the estimates do not take into account future fluctuations in property and asset values. Therefore, the damage estimates should only be considered an approximation.



TWEED SHIRE COUNCIL

Figure Extent

LEGEND

Average Annual Damages

- > $10,000
- $5,000 - $10,000
- $2,500 - $5,000
- $1,000 - $2,500
- $0 - $1,000

Notes:

Aerial photograph date: 2015

N W E S

0 0.25 0.5 Km

Average Annual Damage

Prepared By:

Catchment Simulation Solutions
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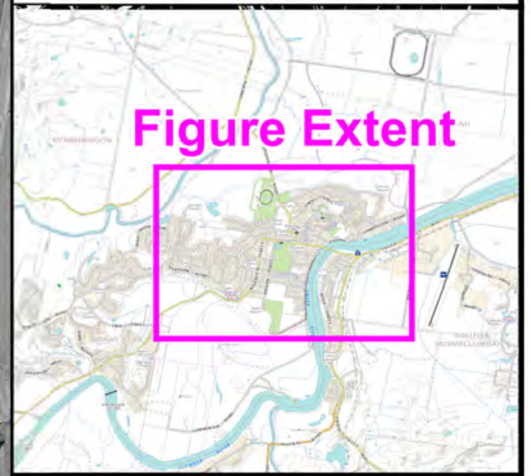
Sydney, NSW 2000

File Name: Average Annual Damages.wor

APPENDIX H

CONCEPT DESIGN PLANS

TWEED SHIRE COUNCIL



LEGEND

Cut / Fill (m)

- -2.50
- -1.00
- -0.50
- -0.10
- No Change
- 0.10
- 0.50
- 1.00
- 2.50

Notes:
Aerial photograph date: 2015

N W E S

0 0.25 0.5 Km

Figure H1: Levee Raising Locations

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Catchment Simulation Solutions
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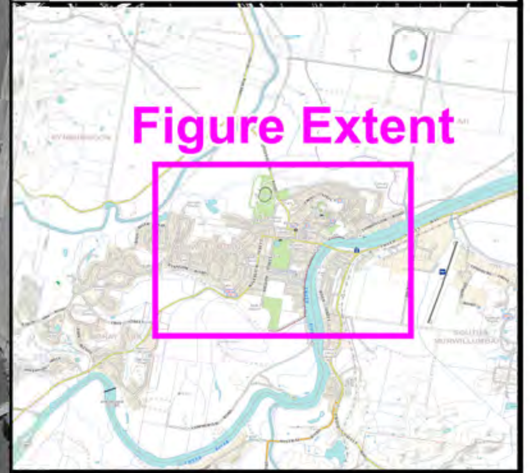
Sydney, NSW 2000

File Name: Fig H1 - Levee Raising.wor

TWEED SHIRE COUNCIL



LEGEND

Notes:
Aerial photograph date: 2015

N
W E
S

0 0.25 0.5
Km

Figure H2: Additional Pump Locations

Prepared By:
Catchment Simulation Solutions
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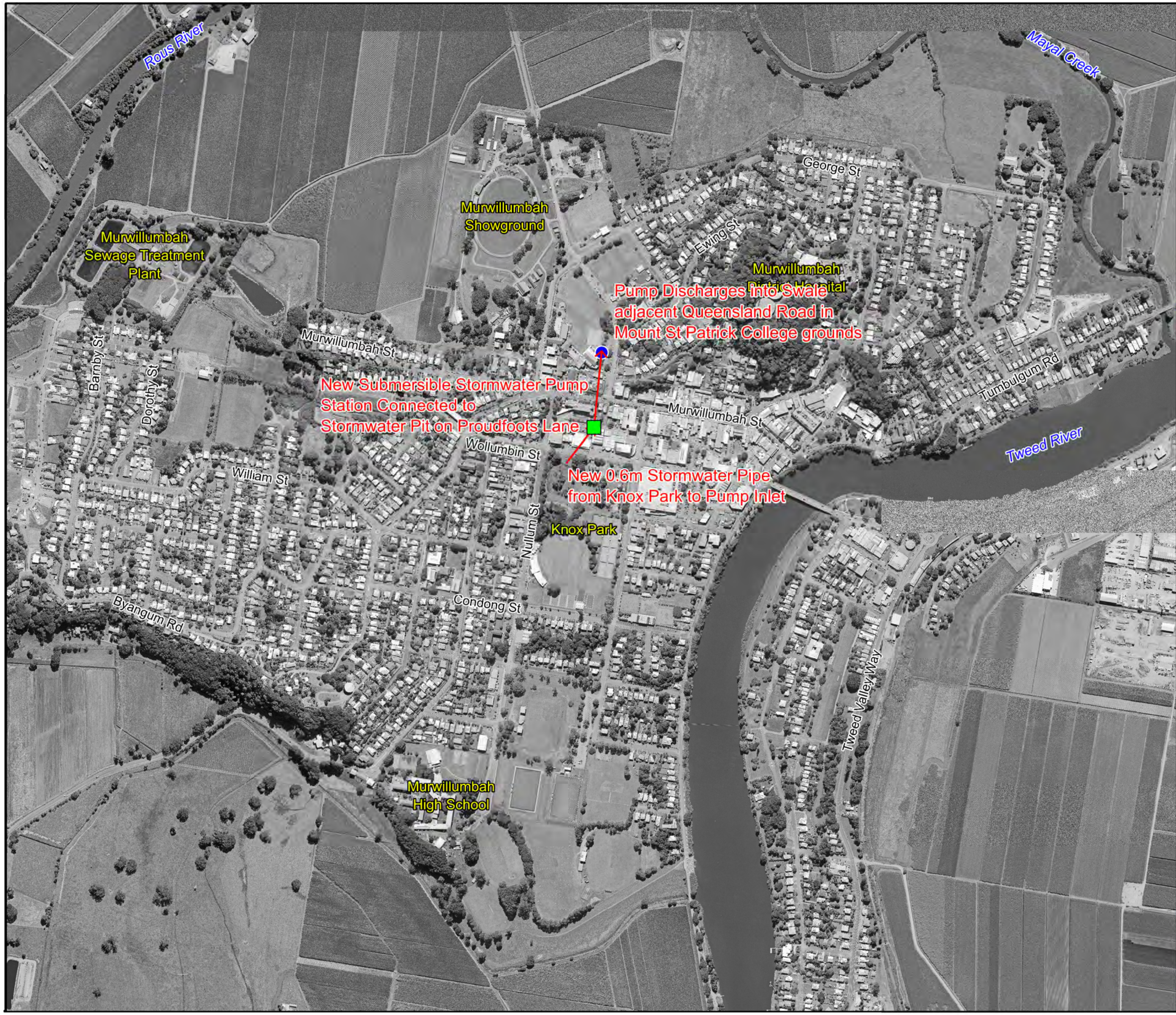
Sydney, NSW 2000

File Name: Fig H2 - Additional Pumps.wor



TWEED SHIRE COUNCIL

Figure Extent

LEGEND

Notes:

Aerial photograph date: 2015

N W E S

0 0.25 0.5 Km

Figure H3: Proudfoots Pump Location

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Sydney, NSW 2000

File Name: Fig H3 - Proudfoots Pump.wor

TWEED SHIRE COUNCIL

Figure Extent

LEGEND

Cut / Fill (m)

- -2.50
- -1.00
- -0.50
- -0.10
- No Change
- 0.10
- 0.50
- 1.00
- 2.50

Notes:

Aerial photograph date: 2015

N W E S

0 0.25 0.5 Km

Figure H4: Road Regrade Locations

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Catchment Simulation Solutions
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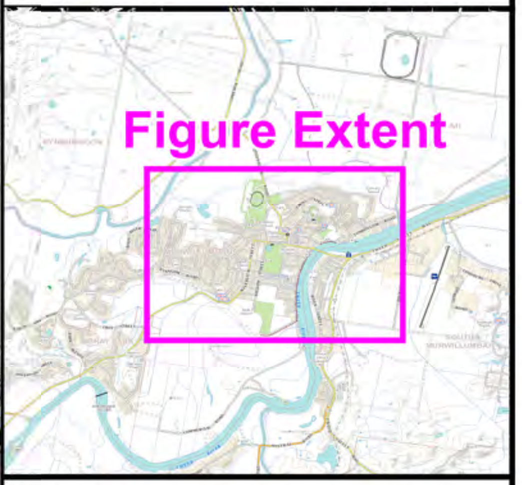
Sydney, NSW 2000

File Name: Fig H4 - Road Regrades.wor

TWEED SHIRE COUNCIL



LEGEND

Stormwater Network

- Existing Stormwater Pipe
- Duplicated Stormwater Pipe
- New Stormwater Pipe

Notes:

Aerial photograph date: 2015

N W E S

0 0.25 0.5 Km

Figure H5: Stormwater Upgrade Locations

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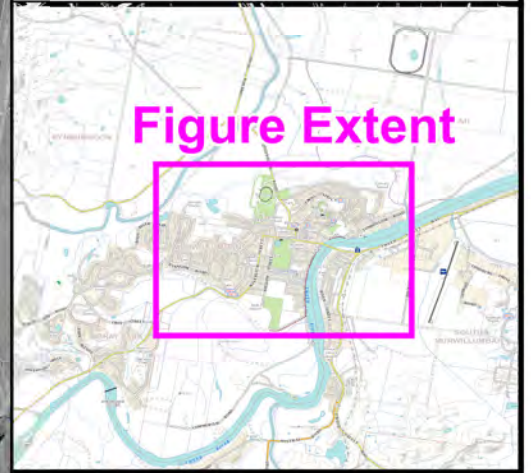
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Fig H5 - Stormwater Upgrades.wor

TWEED SHIRE COUNCIL



LEGEND

Notes:
Aerial photograph date: 2015

N
W E
S

0 0.25 0.5
Km

Figure H6: Levee Gate Modification Locations

Prepared By:
Catchment Simulation Solutions
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Sydney, NSW 2000

File Name: Fig H6 - Levee Gates.wor

APPENDIX I

COST ESTIMATES

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option A - Levee Raising

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared. Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

Reg. Index: 1.05

	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$31,300**
	1.01	Site Establishment (allowance only)	Lump sum	1	10,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	10,000	$10,000
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	0	$0
	1.04	OHS&R Plan	Lump sum	1	4,000	$4,000
	1.05	QA & ITP	Lump sum	1	4,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	0	$0
	1.07	Erosion and Sediment control - Geotextile Silt Fence around site	m	200	16.50	$3,300
2		**EARTHWORKS**				**$2,589,235**
	2.01	Excavate over site to reduce levels (clay)	m3	10367	16.00	$174,172
	2.02	Prepare foundations (light soil) up to 0.5m deep	m3	1500	36.70	$57,794
	2.03	Embankment Fill Material (locally sourced appropriate impervious fill)	m2	10798	140	$1,587,359
	2.04	Place and compact fill (to 90%) for levee embankment (clay)	m3	10798	13.30	$150,799
	2.05	Place and trim excavated fill and topsoil to levee	m3	11170	12.50	$146,610
	2.07	Concrete and Rip-rap lining of spillway (river gravel and concrete)	m3	4500	100.00	$472,500
3		**LANDSCAPING**				**$7,418**
	3.01	Sprayed Grass Seed Compound Hydro Mulch	m2	22076	0.32	$7,418
4		**SITE RESTORATION**				**$10,500**
	4.01	Site Restoration	Lump sum	1	10,000	$10,500
5		**SURVEY AND DOCUMENTATION**				**$30,000**
	5.01	Operations and Maintenance Manual Updates	Lump sum	1	5,000	$5,000
	5.02	Survey and Work-As-Executed Drawings	Lump sum	1	25,000	$25,000
6		**OPERATION AND MAINTENANCE**				**$0**
	6.01	Levee Maintenance (inspections/maintenance of entire levee once every 3 years) **(NPV @ 7%)**	Item	0	199,879	$0
					SUBTOTAL	**$2,668,453**
7		**ENGINEERING DESIGN**				**$266,845**
	7.01	Investigation and Preparation of engineering design plans (10%)				$266,845
8		**PROJECT MANAGEMENT**				**$560,375**
	8.01	Construction management/supervision (12%)				$320,214
	8.02	Project Management (9%)				$240,161
9		**OTHER CONTINGENCIES**				**$1,067,381**
	9.01	General (40%)				$1,067,381
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$4,560,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option B1 - Upgraded Pump System within Commercial Rd Levee

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

Reg. Index: 1

	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$88,660**
	1.01	Site Establishment (allowance only)	Lump sum	1	4,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	4,000	$10,000
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	4,000	$10,000
	1.04	OHS&R Plan	Lump sum	1	2,000	$4,000
	1.05	QA & ITP	Lump sum	1	2,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	50,000	$50,000
	1.07	Erosion and Sediment control - Geotextile Silt Fence around site	m	40	16.50	$660
2		**EARTHWORKS**				**$11,284**
	2.01	Excavation of strip of roadway/embankment for new pump outlet pipes (excavate trench 1-2m in soft rock)	m3	33	87	$2,871
	2.02	Preparation and site movement of pumps/pipes (via crane)	Lump sum	1	8,000	$8,000
	2.03	Backfilling excavated (on-site) material	m3	33	13	$413
3		**PITS TO HOUSE PUMPS**				**$4,475**
	3.01	Excavation/backfilling for pumps and outlet headwall/flood gate	m3	14	87	$1,175
	3.02	Insitu concrete pit to house pump inlet configuration (assume 0.9mx0.9mx0.9m deep)	each	2	1,650	$3,300
4		**FLOOD GATES**				**$30,000**
	4.01	Flood Gate (Supply and Commission) - to suit 1.2m diameter outlet	each	2	15,000	$30,000
5		**DRAINAGE INFASTRUCTURE**				**$51,975**
	5.01	1.05m RCP (Class 3)	m	33	1,575	$51,975
6		**PUMPS AND PUMP STATION**				**$50,000**
	6.01	Permanent Drainage Pump with high flow outlet (2000L/s)	each	0	300,000	$0
	6.02	Permanent Drainage Pump Augmentation at Lavender Creek Pump Station	each	1	25,000	$25,000
	6.03	Permanent Drainage Pump Augmentation at CBD Pump Station	each	1	25,000	$25,000
	6.04	Construction and Fixing of elevated pump station (steel fabrication)	each	0	55,000	$0
7		**ROAD WORKS**				**$1,772**
	7.01	Install new pavement (hot bitumous concrete incl. tack coat)-40mm thick	m2	40	20.50	$820
	7.02	Install kerb & gutter (600 x 225mm)	m	20	47.60	$952
8		**LANDSCAPING**				**$0**
	8.01	Turf, laid, rolled & watered for 2 weeks immediately around installed flood gates	m2	0	8.75	$0
9		**OPERATION AND MAINTENANCE**				**$142,115**
	9.01	Flood Gate Maintenance (inpections/cleaning x 4 times per year x 50 years) (NPV @ 7%)	Item	1	44,162	$44,162
	9.02	Flood Gate Component Replacement at year 25 (assuming current cost (NPV @ 7%)	Item	1	1,382	$1,382
	9.03	Pump Operation (2 weeks / year) (NPV @ 7%)	Item	1	2,654	$2,654
	9.04	Pump Maintenance (6 monthly) (NPV @ 7%)	Item	1	38,642	$38,642
	9.05	Pump Replacement at Year 25 (NPV @ 7%)	Item	1	55,275	$55,275
					SUBTOTAL	**$380,280**
10		**ENGINEERING DESIGN**				**$38,028**
	10.01	Preparation of engineering design plans (10%)				$38,028
11		**PROJECT MANAGEMENT**				**$76,056**
	11.01	Supervision, Project Management etc (20%)				$76,056
12		**OTHER CONTINGENCIES**				**$152,112**
	12.01	General (40%)				$152,112
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$650,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option B2 - New Pump System within East Murwillumbah Levee

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

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	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$88,660**
	1.01	Site Establishment (allowance only)	Lump sum	1	4,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	4,000	$10,000
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	4,000	$10,000
	1.04	OHS&R Plan	Lump sum	1	2,000	$4,000
	1.05	QA & ITP	Lump sum	1	2,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	50,000	$50,000
	1.07	Erosion and Sediment control - Geotextile Silt Fence around site	m	40	16.50	$660
2		**EARTHWORKS**				**$11,284**
	2.01	Excavation of strip of roadway/embankment for new pump outlet pipes (excavate trench 1-2m in soft rock)	m3	33	87	$2,871
	2.02	Preparation and site movement of pumps/pipes (via crane)	Lump sum	1	8,000	$8,000
	2.03	Backfilling excavated (on-site) material	m3	33	13	$413
3		**PITS TO HOUSE PUMPS**				**$2,825**
	3.01	Excavation/backfilling for pumps and outlet headwall/flood gate	m3	14	87	$1,175
	3.02	Insitu concrete pit to house pump inlet configuration (assume 0.9mx0.9mx0.9m deep)	each	1	1,650	$1,650
4		**FLOOD GATES**				**$15,000**
	4.01	Flood Gate (Supply and Commission) - to suit 1.2m diameter outlet	each	1	15,000	$15,000
5		**DRAINAGE INFASTRUCTURE**				**$31,185**
	5.01	1.05m RCP (Class 3)	m	20	1,575	$31,185
6		**PUMPS AND PUMP STATION**				**$355,000**
	6.01	Permanent Drainage Pump with high flow outlet (2000L/s)	each	1	300,000	$300,000
	6.04	Construction and Fixing of elevated pump station (steel fabrication)	each	1	55,000	$55,000
7		**LANDSCAPING**				**$263**
	7.01	Turf, laid, rolled & watered for 2 weeks immediately around installed flood gates	m2	30	8.75	$263
8		**OPERATION AND MAINTENANCE**				**$71,058**
	8.01	Flood Gate Maintenance (inpections/cleaning x 4 times per year x 50 years) (NPV @ 7%)	Item	1	22,081	$22,081
	8.02	Flood Gate Component Replacement at year 25 (assuming current cost (NPV @ 7%)	Item	1	691	$691
	8.03	Pump Operation (2 weeks / year) (NPV @ 7%)	Item	1	1,327	$1,327
	8.04	Pump Maintenance (6 monthly) (NPV @ 7%)	Item	1	19,321	$19,321
	8.05	Pump Replacement at Year 25 (NPV @ 7%)	Item	1	27,637	$27,637
					SUBTOTAL	**$575,273**
9		**ENGINEERING DESIGN**				**$57,527**
	9.01	Preparation of engineering design plans (10%)				$57,527
10		**PROJECT MANAGEMENT**				**$115,055**
	10.01	Supervision, Project Management etc (20%)				$115,055
11		**OTHER CONTINGENCIES**				**$230,109**
	11.01	General (40%)				$230,109
					TOTAL at 7% NPV (Rounded to nearest $10,000)	**$980,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option B3 - New Pump System within Dorothy St Levee

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

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Item		Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$88,660**
	1.01	Site Establishment (allowance only)	Lump sum	1	4,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	4,000	$10,000
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	4,000	$10,000
	1.04	OHS&R Plan	Lump sum	1	2,000	$4,000
	1.05	QA & ITP	Lump sum	1	2,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	50,000	$50,000
	1.07	Erosion and Sediment control - Geotextile Silt Fence around site	m	40	16.50	$660
2		**EARTHWORKS**				**$11,284**
	2.01	Excavation of strip of roadway/embankment for new pump outlet pipes (excavate trench 1-2m in soft rock)	m3	33	87	$2,871
	2.02	Preparation and site movement of pumps/pipes (via crane)	Lump sum	1	8,000	$8,000
	2.03	Backfilling excavated (on-site) material	m3	33	13	$413
3		**PITS TO HOUSE PUMPS**				**$2,825**
	3.01	Excavation/backfilling for pumps and outlet headwall/flood gate	m3	14	87	$1,175
	3.02	Insitu concrete pit to house pump inlet configuration (assume 0.9mx0.9mx0.9m deep)	each	1	1,650	$1,650
4		**FLOOD GATES**				**$15,000**
	4.01	Flood Gate (Supply and Commission) - to suit 1.2m diameter outlet	each	1	15,000	$15,000
5		**DRAINAGE INFASTRUCTURE**				**$31,185**
	5.01	1.05m RCP (Class 3)	m	20	1,575	$31,185
6		**PUMPS AND PUMP STATION**				**$355,000**
	6.01	Permanent Drainage Pump with high flow outlet (2000L/s)	each	1	300,000	$300,000
	6.04	Construction and Fixing of elevated pump station (steel fabrication)	each	1	55,000	$55,000
7		**LANDSCAPING**				**$263**
	7.01	Turf, laid, rolled & watered for 2 weeks immediately around installed flood gates	m2	30	8.75	$263
8		**OPERATION AND MAINTENANCE**				**$71,058**
	8.01	Flood Gate Maintenance (inpections/cleaning x 4 times per year x 50 years) (NPV @ 7%)	Item	1	22,081	$22,081
	8.02	Flood Gate Component Replacement at year 25 (assuming current cost (NPV @ 7%)	Item	1	691	$691
	8.03	Pump Operation (2 weeks / year) (NPV @ 7%)	Item	1	1,327	$1,327
	8.04	Pump Maintenance (6 monthly) (NPV @ 7%)	Item	1	19,321	$19,321
	8.05	Pump Replacement at Year 25 (NPV @ 7%)	Item	1	27,637	$27,637
					SUBTOTAL	**$575,273**
9		**ENGINEERING DESIGN**				**$57,527**
	9.01	Preparation of engineering design plans (10%)				$57,527
10		**PROJECT MANAGEMENT**				**$115,055**
	10.01	Supervision, Project Management etc (20%)				$115,055
11		**OTHER CONTINGENCIES**				**$230,109**
	11.01	General (40%)				$230,109
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$980,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option C - Proudfoots Lane Pump System

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

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Item		Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$78,000**
	1.01	Site Establishment (allowance only)	Lump sum	1	10,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	0	10,000	$0
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	10,000	$10,000
	1.04	OHS&R Plan	Lump sum	1	4,000	$4,000
	1.05	QA & ITP	Lump sum	1	4,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	50,000	$50,000
	1.07	Erosion and Sediment control - Geotextile Silt Fence around site	m	0	16.50	$0
2		**EARTHWORKS**				**$14,534**
	2.01	Excavation of roadway for new pump station and inlet/outlet pipes (excavate pits 1-2m in soft rock)	m3	66	87	$5,742
	2.02	Preparation and site movement of pumps/pipes (via crane)	Lump sum	1	8,000	$8,000
	2.03	Backfilling excavated (on-site) material	m3	66	12	$792
3		**PIPE TUNNEL CORING**				**$1,102,000**
	3.01	Tunnel Coring and lining (0.375m diameter) including site establishment costs, microtunnelling, insertion of jacking pipe and connections	m	182	6,000	$1,092,000
	3.02	Reconfiguration of pits on Proudfoots Lane (excavation of existing, installation of new pit and connection to pipe tunnel -excavation of pits in confined spaces - soft rock)	Lump sum	1	10,000	$10,000
4		**PITS TO HOUSE PUMP**				**$12,975**
	4.01	Excavation/backfilling for pumps and outlet headwall/flood gate	m3	14	87	$1,175
	4.02	Insitu concrete pit/headwall to house flood gate (assume 1.5mx1.5mx1.5m)	each	4	2,950	$11,800
5		**DRAINAGE INFASTRUCTURE**				**$43,460**
	5.01	0.6m RCP (Class 3) - Knox Park to proudfoots Lane Pump	m	106	410	$43,460
6		**PUMPS AND PUMP STATION**				**$300,000**
	6.01	Submersible Drainage Pump with high flow outlet (2000L/s)	each	1	300,000	$300,000
7		**ROAD WORKS**				**$1,772**
	7.01	Install new pavement (hot bitumous concrete incl. tack coat)-40mm thick	m2	40	20.50	$820
	7.02	Install kerb & gutter (600 x 225mm)	m	20	47.60	$952
8		**OPERATION AND MAINTENANCE**				**$48,285**
	8.01	Pump Operation (2 weeks / year) (NPV @ 7%)	Item	1	1,327	$1,327
	8.02	Pump Maintenance (6 monthly) (NPV @ 7%)	Item	1	19,321	$19,321
	8.03	Pump Replacement at Year 25 (NPV @ 7%)	Item	1	27,637	$27,637
					SUBTOTAL	**$1,601,026**
9		**ENGINEERING DESIGN**				**$160,103**
	9.01	Preparation of engineering design plans (10%)				$160,103
10		**PROJECT MANAGEMENT**				**$320,205**
	10.01	Supervision, Project Management etc (20%)				$320,205
11		**OTHER CONTINGENCIES**				**$640,410**
	11.01	General (40%)				$640,410
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$2,720,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option D - Regrading of William Street and Wharf Street

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

Reg. Index: 1

	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$26,157**
	1.01	Site Establishment (allowance only)	Lump sum	1	4,000	$4,000
	1.02	QA & ITP	Lump sum	1	4,000	$4,000
	1.03	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	2,000	$2,000
	1.04	OHS&R Plan	Lump sum	1	2,000	$2,000
	1.05	Erosion and Sediment control - Geotextile Silt Fence around site	m	858	16.50	$14,157
2		**EARTHWORKS**				**$569,182**
	2.01	Excavate over site to reduce levels (clay) (downstream of William St) - average 1m cut	m3	790	16	$12,640
	2.02	Earthworks to demolish existing roadway surface (hard rock) (Reduce levels and deposit within 500m, hard rock (asphalt/concrete))	m3	1596	93	$148,081
	2.03	Bulk excavate over site to reduce levels (clay) where roadway will be lowered and deposit in spoil heaps within 3km	m3	3079	9	$27,311
3		**ROAD WORKS**				**$219,790**
	3.01	Laying of new roadway to specified minimum elevation (incl regrade, new base and seal) - 8m wide composite	m	400	435	$174,000
	3.02	Lay reinforced concrete slab adjacent Wharf St (150mm thick slab on fill, including placement)	m2	190	241	$45,790
4		**LANDSCAPING AND POST TREATMENT**				**$6,913**
	4.01	Turf, laid, rolled & watered for 2 weeks along William St swale	m2	790	8.75	$6,913
					SUBTOTAL	**$822,041**
5		**ENGINEERING DESIGN**				**$82,204**
	5.01	Preparation of engineering design plans (10%)				$82,204
6		**PROJECT MANAGEMENT**				**$164,408**
	6.01	Supervision, Project Management etc (20%)				$164,408
7		**OTHER CONTINGENCIES**				**$328,816**
	7.01	General (40%)				$328,816
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$1,400,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option E - Drainage Upgrades

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 31, 2013

Reg. Index: 1

	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$101,680**
	1.01	Site Establishment (allowance only)	Lump sum	1	10,000	$10,000
	1.02	Water Management Plan incl. Erosion and Sediment Control Plan	Lump sum	1	10,000	$10,000
	1.03	Traffic/Pedestrian Management Plan	Lump sum	1	10,000	$10,000
	1.04	OHS&R Plan	Lump sum	1	4,000	$4,000
	1.05	QA & ITP	Lump sum	1	4,000	$4,000
	1.06	Relocate Services (allowance only)	Lump sum	1	50,000	$50,000
	1.07	Erosion and Sediment control - Floating Silt Curtain	m	228	60	$13,680
2		**EARTHWORKS**				**$78,596**
	2.01	Excavation of roadway along alignment of new pipes and location of new pits (Excavate trenches less than 1m deep in soft rock)	m3	90	87	$7,840
	2.02	Excavation of ground beneath roadway along alignment of new pipes (Excavate trenches between 1-2m deep in clay) including backfilling excavated (on-site) material	m3	1061	67	$70,755
3		**PIPE TUNNEL CORING**				**$569,800**
	3.01	Tunnel Coring and lining (0.375m diameter) including site establishment costs, microtunnelling, insertion of jacking pipe and connections	m	177	3,000	$529,800
	3.02	Reconfiguration of pits on Proudfoots Lane and Nullum St (excavation of existing, installation of new pit and connection to pipe tunnel -excavation of pits in confined spaces - soft rock)	Lump sum	4	10,000	$40,000
4		**DRAINAGE INFASTRUCTURE**				**$330,989**
4.1		**Circular Pipes**				*$320,945*
	4.1.1	0.375m RCP (Class 3)	m	270	192	$51,802
	4.1.2	0.45m RCP (Class 3)	m	16	255	$4,029
	4.1.3	0.6m RCP (Class 3)	m	30	365	$10,950
	4.1.4	0.75m RCP (Class 3)	m	26	520	$13,572
	4.1.5	1.2m RCP (Class 4)	m	189	1,275	$240,593
4.2		**Stormwater Pits**				*$3,720*
	4.2.1	New precast concrete pit (assume 0.9mx0.9m)	each	4	930	$3,720
4.3		**Stormwater Inlets**				*$6,324*
	4.3.1	Kerb inlet with grate & 2.4m lintel	No.	4	1,200	$4,800
	4.3.2	0.9m square pit with grated inlet (single unit cover)	No.	2	762	$1,524
5		**ROAD WORKS**				**$1,772**
	5.01	Install new pavement (hot bitumous concrete incl. tack coat)-40mm thick	m2	40	20.50	$820
	5.02	Install kerb & gutter (600 x 225mm)	m	20	47.60	$952
6		**LANDSCAPING**				**$2,013**
	6.01	Turf, laid, rolled & watered for 2 weeks along alignment of new pipeline under grass	m2	230	8.75	$2,013
					SUBTOTAL	**$515,049**
7		**ENGINEERING DESIGN**				**$51,505**
	7.01	Preparation of engineering design plans (10%)				$51,505
8		**PROJECT MANAGEMENT**				**$103,010**
	8.01	Supervision, Project Management etc (20%)				$103,010
9		**OTHER CONTINGENCIES**				**$206,020**
	9.01	General (40%)				$206,020
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$880,000**

PRELIMINARY COST ESTIMATE

Description of Works Revision: 1

Option F - Commercial Road Levee Gate Modifications

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

Reg. Index: 1

Item		Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$5,000**
	1.01	Site Establishment (allowance only)	Lump sum	1	2,000	$2,000
	1.02	Traffic/Pedestrian Management Plan	Lump sum	1	2,000	$2,000
	1.03	OHS&R Plan	Lump sum	1	1,000	$1,000
2		**HINGES**				**$10,520**
	2.01	Heavy Duty Hinges for levee gates	pair	3	840	$2,520
	2.02	Installation by suitable qualified and experienced personnel	each	1	8,000	$8,000
3		**OPERATION AND MAINTENANCE**				**$28,964**
	3.01	Levee Gate Hinge Maintenance (6 monthly) (NPV @ 7%)	Item	1	1,327	$1,327
	3.02	Levee Gate Hinge Replacement at Year 25 (NPV @ 7%)	Item	1	27,637	$27,637
					SUBTOTAL	**$44,484**
4		**ENGINEERING DESIGN**				**$4,448**
	4.01	Preparation of engineering design plans (10%)				$4,448
5		**PROJECT MANAGEMENT**				**$8,897**
	5.01	Supervision, Project Management etc (20%)				$8,897
6		**OTHER CONTINGENCIES**				**$2,224**
	6.01	General (5%)				$2,224
			TOTAL at 7% NPV (Rounded to nearest $10,000)			**$60,000**

PRELIMINARY COST ESTIMATE

Description of Works	Revision: 1
Flood Barriers on Commercial Properties (1m high)	

Note: The preliminary costs estimates outlined below have been prepared for comparing and evaluating the feasibility of different drainage mititgation options. They are approximate only and should not be relied upon for budgetting purposes. Detailed costings can only be prepared once detailed design plans are prepared.
Cost estimates only include capital costs and no ongoing maintenance costs are included unless specifically noted.

Reference: Rawlinsons 'Australian Construction Handbook' - Edition 34, 2016

Reg. Index: 1

	Item	Description	Unit	Quantity	Base Rate	Amount
1		**PRELIMINARY ITEMS**				**$260**
	1.01	Site Establishment (allowance only)	m	1	260	$260
2		**FLOOD BARRIER**				**$12,600**
	2.01	Heavy Duty Demountable Flood Barriers (0.9m high x 1 metre length)	m	5	2,200	$11,000
	2.02	Installation by suitable qualified and experienced personnel	m	5	320	$1,600
3		**OPERATION AND MAINTENANCE**				**$6,624**
	3.01	Horizontal Base (to ground) Seal Replacement (every 10 years) (NPV @ 7%)	m	5	442	$2,208
	3.02	Horizontal Seal Replacement (every 10 years) (NPV @ 7%)	m	5	883	$4,416
					SUBTOTAL	**$19,484**
4		**PROJECT MANAGEMENT**				**$974**
	4.01	Supervision, Project Management etc (5%)				$974
5		**OTHER CONTINGENCIES**				**$974**
	5.01	General (5%)				$974
					TOTAL at 7% NPV (Rounded to nearest $1,000)	**$21,000**

Appendix J

Community Consultation

Murwillumbah Flood Levee and Drainage Study

Flooding is the most costly natural disaster in Australia, causing an estimated $314 million of damage every year. More than 2000 people have died in floods in Australia.

Tweed Shire Council has commissioned specialist flood consultants Catchment Simulation Solutions to undertake a Murwillumbah Flood Levee and Drainage Study to build on previous flood investigations and provide Council and emergency services with a detailed understanding of the existing inundation problem across Murwillumbah.

The study also will help identify measures that will best reduce the frequency, extent and depth of inundation and guide future development and re-development in a way that is compatible with the inundation 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

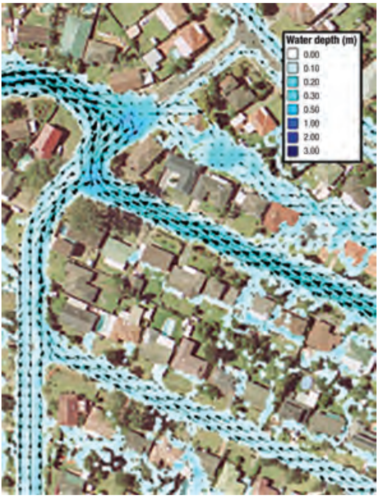
The study area comprises central Murwillumbah, including the CBD, and is shown on the image on the front page. South Murwillumbah is not included but is likely to be the subject of a future study.

The study area was inundated in the floods of 1954, 1974 and most recently in March 2017. The CBD can be inundated when the levee system is overtopped from the Tweed River and/or Rous River, as well as when local rainfall builds up behind the levee.

Inundation of the study area has the potential to cut roads and cause damage to both commercial and residential properties. During severe events, it also could pose 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 Central Murwillumbah during a range of different floods and quantify the benefits provided by a range of potential mitigation options and/or upgrades (e.g. stormwater or pump upgrades). An example of the type of floodwater depth and 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 enclosed 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

Leon McLean, Tweed Shire Council
(02) 6670 2691 • lmclean@tweed.nsw.gov.au

More information can be found at www.murwillumbah.floodstudy.com.au

Murwillumbah Flood Levee and Drainage Study Questionnaire

TWEED
SHIRE COUNCIL

To assist Tweed Shire Council complete a detailed drainage and flood levee overtopping study for Murwillumbah, can you please fill in this questionnaire and return it by 18 November 2017. You can return it in the reply-paid envelope provided or via email to dtetley@csse.com.au or lmclean@tweed.nsw.gov.au

To complete the questionnaire online, please go to www.murwillumbah.floodstudy.com.au

Contact details

Please provide your details so we can contact you in case we need more information. Your contact details will remain confidential and only be used for the purpose of this study.

Name: ....

Address: .... Phone: ....

.... Email: ....

1 What type of property do you have?

☐ Residential ☐ Commercial
☐ Industrial ☐ Vacant land
☐ Other (please specify):

....

....

2 With respect to this property are you …

☐ The owner ☐ The tenant
☐ A business person ☐ Other (please specify):

....

3 Have you experienced floods in this area?

☐ Yes – what years? ☐ No (go to question 5)

....

4 How did the biggest of these floods affect you?

(Tick **all** that apply)

☐ Water over main building floor – please describe depth:

.... metres

☐ Water in garage and sheds – please describe depth:

.... metres

☐ Lost access due to flooding of roads – which roads and for how long?

....

....

☐ Not applicable/not affected ☐ Other (please specify):

....

....

5 Do you know if your house/business has a risk of being flooded? (Tick **one** only)

☐ Yes, I know my house/business could be flooded
☐ Yes, I know my house/business cannot be flooded
☐ No, I don't know/I'm not sure if my house/business could be flooded (go to question 7)

6 Do you know if what size of flood your house/business could be affected? (Tick **one** only)

☐ My house/business could be flooded in a so-called 1% AEP (1 in 100 year) flood
☐ My house/business could be flooded in a so-called probable maximum flood
☐ My house/business could be flooded but I'm not sure of the name of the flood

7 How do you think you would respond to a major flood in this area? (Tick **one** only)

☐ Evacuate early to an official evacuation centre in Murwillumbah
☐ Evacuate elsewhere – please describe:

....

....

☐ Remain at my house ☐ Don't know/not sure
☐ Other – please describe

....

....

....

....

8 If you are likely to evacuate, what factors are most important to you?

Please rank the following options from 1 (most important) to 5 (least important):

- ☐ 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:

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

9 If you are likely to remain at your house, what factors are most important to you?

Please rank the following options from 1 (most important) to 6 (least important):

- ☐ 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:

……………………………………………………………………………………

……………………………………………………………………………………

10 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
Increase height of East Murwillumbah and Commercial Road levees	☐	☐	☐	☐	☐	☐
Upgrade of existing CBD levee pump systems and installation of new pumps behind East Murwillumbah and Dorothy Street/Brothers levees	☐	☐	☐	☐	☐	☐
New pump system in Proudfoots Lane	☐	☐	☐	☐	☐	☐
Regrading of Williams Street (near Dorothy Street) and near the intersection of Commercial Road/Wharf Street to drain water away from existing residential and commercial properties	☐	☐	☐	☐	☐	☐
Stormwater upgrades in Proudfoot Lane, Nullum Lane and William Street	☐	☐	☐	☐	☐	☐
Re-design of Commercial Road levee gates to allow gates to open and release water trapped behind the levee as flood recedes	☐	☐	☐	☐	☐	☐

Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or improve the resilience of buildings.	Strongly against	Against	Neutral	Support	Strongly support	Unsure
Modifications to Council's planning documents to reduce population intensification in high-risk areas	☐	☐	☐	☐	☐	☐
Temporary flood barriers to prevent ingress of floodwaters into commercial properties	☐	☐	☐	☐	☐	☐

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
Updates to SES Local Flood Plan	☐	☐	☐	☐	☐	☐
Real-time flood gauging and warning system	☐	☐	☐	☐	☐	☐
Community education programs	☐	☐	☐	☐	☐	☐

11 Do you have any other suggestions for reducing flooding problems than those listed above? Please describe.

………

………

………

………

………

………

………

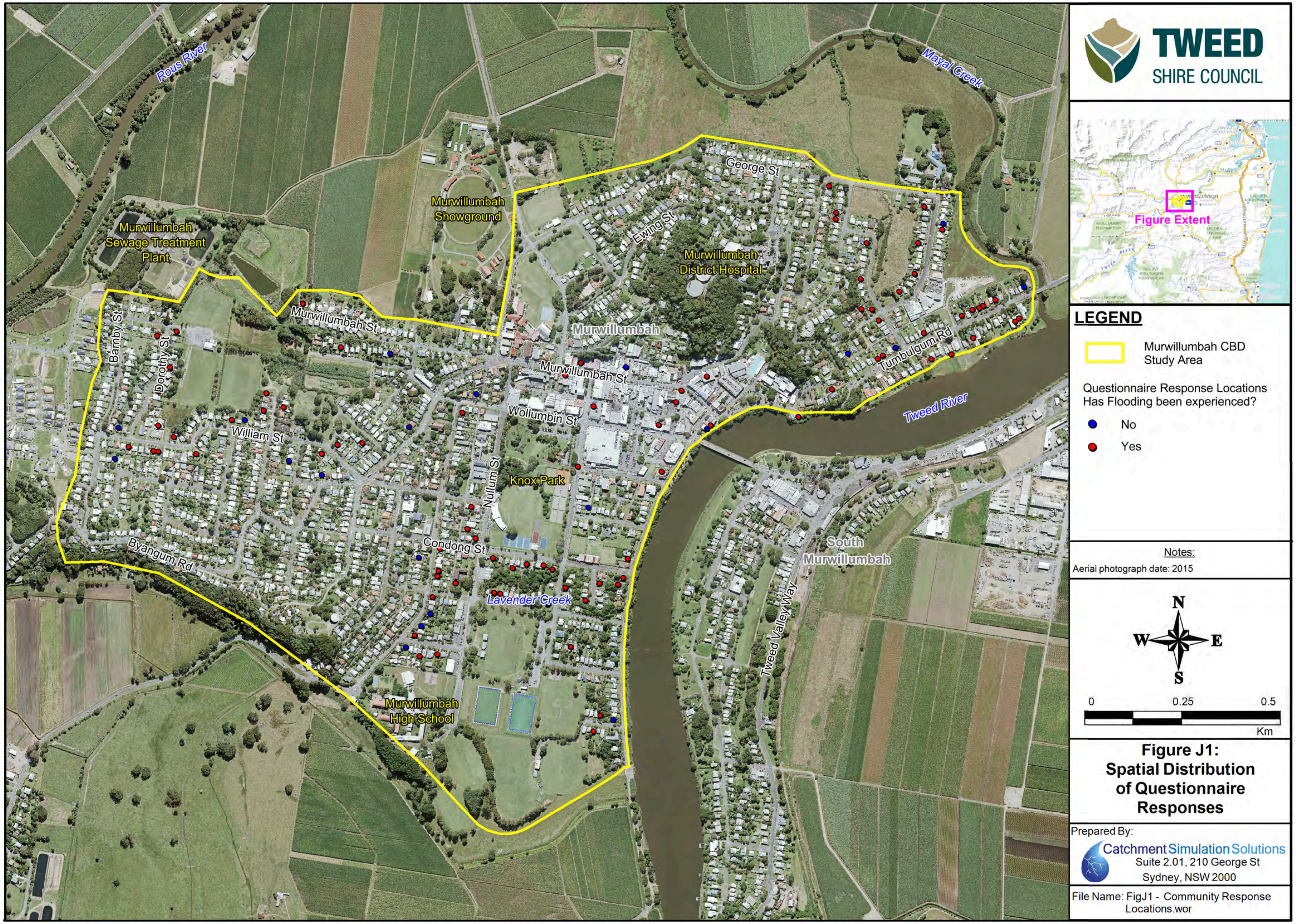


Figure J1: Spatial Distribution of Questionnaire Responses

Table J1 - Response to Flood Impacts and Evacuation Options

#	What type of property do you have?					With respect to this property are you...				Have you Experinced Floods In this Area?			How did the biggest of these floods affect you? (tick all that apply)							
	Residential	Commerical	Industrial	Vacant land	Other (please specify)	The owner	The tenant	A business person	Other (please specify)	Yes	Years	No	Water over main building	please describe depth:	Water in garage and sheds	please describe depth:	Lost access due to flooding of roads	please describe depth:	not applicable/ not affected	Other (please specify)
1	X					X				X	every flood				X	1	X	James St,James Lane Brisbane St,other Surrounding		
2	X					X				X			X	1,1974-last time		5	Hartigan St brisbane St,Nullum St 1-2 Dats			
3	X					X				X	Feb-00				X	15 (2017 STORM WATER ONLY)				
4		X				X				X			X				X			
5	X					X						X								
6	X					X				X	2017				X	1	X	Condong St Brisbane St		
7	X					X				X				2		1		2 DAYS		
8	X					X													X	
9		X				X						X							X	
10	X					X						X								
11	X					X				X	2017				X	1/2 METER	X	Tumulgum Rd 5 Days		
12	X					X				X	2017									Flooded at end of road no acess to highchud leve for ternnath
13		X				X	X			X										water entered leves level treament room when old rsh club
14	X						X			X	20,172,012				X	1	X	TWEED VALLEY WAY-1 WEEK BRISBANE ST, COMMERCIAL Rd- 3 DAYS		
15	X					X				X	2017								X	Residents across the road got destoryed
16		X					X			X			X	3						
17	X						X					X								
18	X					X				X	we have lived here since 1984						X			
19	X					X						X								
20	X					X				X	1974			2.1	X		X			
21	X					X				X							X			
22	X					X				.		X								
23	X					X				X	2017						X	willion st,flances st until it went down		back yard from league club - 1 m
24	X					X				X	2017						X	west end street : 2 days		
25	X					X				X	2017						X			
26		X				X				X	2017,2015, 2014		X	1				the pumps that pump out the water in the CBD Faked		
27	X					X				X	Mar-17								X	close
28	X					X				X	every time there is a flood						X	nollom lane -1 week or so		
29	X					X				X					X	2.3 metre	X			
30	X					X				X	1974-1989-2014 several minor floods			one metre						1974 flood entered house 1989 one metre under house.2017 500mm under house
31	X					X				X	all floods in last 3 years				X	1.2 metre	X			
32		X					X			X	1989-2017		X	0.15 metres						
33	X					X				X							X			
34	X					X				X	since 1996						X	some local ! town roads cut, could n't leave mur-bah		sewer overflowed backwards through my property &pipes due to being on end of line etc. long story ! Council couldn't help.happen s in big storm also
35	X					X						X								
36	X					X				X	2017				X					
37	X					X				X	31 march, jan 2005, may 2009				X	0.6 metres				
38	X						X			X	2017						X			

#	Do you know if your house/business has a risk of being flooded (Tick one only)			Do you know if what size of flood your house/ business could be affected? (Tick one only)			How do you think you would respond to a major flood in this area (tick one only)					
	Yes, I know my house/ business could be flooded	Yes, I know my house/ business cannot be flooded	no, I don't know/ I'm not sure if my house/business could be flooded (go to question 7)	My house/business could be flooded 1n a so-called 1% AEP 1 in 100 year) flood	My house/business could be flooded in a so-called probable maximum flood	My house/business could be flooded but I'm not sure of the name of the flood	Evacuate early to an official evacuation centre in Murwillumbah	Evacuate else where	Remain at my house	Don't know/not sure	Other	please describe:
1		X			X					X		
2	X			X	X			X				
3	X			X					X			
4	X					X	X				X	
5		X				X	X					
6	X			X	X				X			
7	X			X					X			
8		X		X					X			
9	X						X					
10		X							X			
11		X				X			X			
12		X				X			X			
13			X	X	X			X				
14	X						X				X	depending on height at
15			X						X			cant drive
16	X			X	X				X			
17			X						X			
18		X							X			
19		X							X			
20	X				X				X			
21	X			X			X					
22		X							X			
23	X			X						X		
24		X					X		X			What about South murwkumbah flood levee
25		X				X	X					
26	X			X			X					
27	X			X					X			
28			X						X			2017 was the worst flood on record water did not enter gcrage & house is built well above flood levels.we remained in house .all was ok
29	X				X				X			
30	X								X			
31	X				X			X	X			
32	X			X	X	X					X	send stafs home who live in other areas lift up stock &rest go home
33			X			X	X					
34			we were about 4 m above latest flood levee across the road						X		X	move car to up the "hospital Hill" not next to east floeing water here , if it got higher than 2017 or 1954or 1974
35	X			X	X				X			depends on my assessment of the situation at the time
36		X							X			
37	X					X		X				
38	X					X					X	

#	If you are likely to evacuate, what factors are most important to you (Please rank the following options from 1 to 5						If you are likely to remain at your house, what factors are most important to you (Please rank the following options from 1 to 5						
	Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for unin terrupted access to medical facilities	Safety of our family	not applicable (I intend to remain at my house)	Other	please describe:	Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for to care for animals	My house cannot be flooded and we can cope with isolation	Concern for security of my property if I exacuate	not applicable (I intent to evacuate from my house)	Other	please describe:
1			X						X				
2	X									X	1		
3			1	X				X				X	Our living area is above 1/1100 year flood leave - we would evaeuate if it became life threatening
4						EVACUTE BECAUSE OF MEDICAL REASON							
5	2	1	3	4	5		2	4	1	3	5	6	
6													
7				X									ALL LIVING ON SECOND LEVEL
8				X					X		X		
9													
10							4	2	1	3	5	6	
11				X			X	X					
12				X			4	2	1	3	5		THE PROPERTY IS ABOVE 7.5 AHD
13				X							X		
14	1	2	3				3	1		2			
15	3	1	2		4	crack heads stealing/ break-1 whie have has been evacuated						X	
16	2	3	1				3	1		2			
17				X						X			
18				X					X				
19				X			3		1	2			
20				X						X			
21	1	2	3				1	2		3			
22									X				
23					X	I would only evacuate if I would be cut off fiver substanded period of time >like weaks			1	2			
24			1						3				
25			X					X					
26													
27				X					X				
28	2	3	1	4			2	5	4	1	3	6	
29	X			X				X		X			
30													lift things above known flood levels. More vehicles to higher ground
31	3	4	1	2	5		4	2	3	1	6	5	
32	X								X				
33	1	2	3	4	5		1	X	2	3	4	5	this property was not flooded or directly affected 2017 flood
34				X			1			2			I live in walking / driving distance up hill from here t the hospital & town I am very fortunate
35										X			
36								1	2				
37	X									X			
38	2	4	1	3	5		5	4	6	2	3	1	

#	What type of property do you have?					With respect to this property are you…				Have you Experinced Floods In this Area?			How did the biggest of these floods affect you? (tick all that apply)							
	Residential	Commerical	Industrial	Vacant land	Other (please specify)	The owner	The tenant	A business person	Other (please specify)	Yes	Years	No	Water over main building	please describe depth:	Water in garage and sheds	please describe depth:	Lost access due to flooding of roads	please describe depth:	not applicable/ not affected	Other (please specify)
39	X							X				X								
40					church			X		X	1974		X	3 metres			X	2 weeks		
41	X								family owner	X	2017				X	one metre	X			
42	X					X				X	lived in M - BAH- 1969						X			
43	X					X				X	2017				X	one metre	X	nullum street - 3-4 days prince street - 3-4 days		
44	X					X				X	2012 /2013/ 2017				X	i.2				
45	X					X				X	2017 3 previous back to 1993				X	7				
46	X					X						X	X	1.2 metre						
47	X				Flats	X				X	Minor flooding of garden 2017,2015 (I think)						X	48 hours brisbane st		
48		X					X					X								
49	X						X			X	2017				X	0.50 metre	X	willion lane		
50	X					X				X	1954-1956-1974				X	1.5 metre			X	
51	X					X				X	1974, 2017		X	one metre	X	one metre	X			
52	X					X				X	2017-2016				X	0.8 metre				
53	X					X				X	2017						X			
54	X					X						X								
55		X				X		X		X	every flood since 1983		X	0.2 metre	X	0.2 meter				
56	X					X				X	1969-2017				X	1 metre				
57	X					X				X			X	1 cm	X	2-3 meter				
58		X					X			X	2017						X			
59	X					X				X	2017		X	0.3meter	X	1.0 metre	X	William , Duruthy		
60	X					X				X	2000				X	1.0 metre				
61	X					X				X	88, 89, 2015, 2017									
62	X					X				X										Storm water blocked & flooded garage floor
63	X					X						X								
64	X					X						X							X	
65	X					X				X	1974								not affected	
66	X						X			X	several times over past 27 years can't remember exact years		X	2.5metre	X	2.5metre		William & Eveleigh st		
67	X					X						X								
68	X					X				X	most flood since 1954				X	0.3 metre				
69	X					X				X					X	less than 20 cm				
70	X					X				X	2017						X	Tweed Valley way		
71	X					X			By power of Attorney	X	more than 60 years				X	2.1 metre				
72	X					X				X	2017, 2016 , 2015				X	1 metr				
73	X					X				X	2017						X			
74	X					X				X	since 1974								X	
75	X					X				X	1989 2017		X	0.6 metre	X	0.6 metre				
76	X					X				X	appox 4 in the last 10 years				X	1.5 metre	X	3 days		
77		X					X			X									X	
78	X					X				X	2017								X	
79	X					X				X	2017						X			
80	X						X					X								moved in after flood
81	X					X													X	
82	X						X			X	2017				X	1.2 metre	X	2 days Dorothy st, William st		
83	X					X				X	2017						X			
84	X					X				X	1945 , 1954 , 1974		X	1 metre	X	2 metre		commercial RD		
85	X					X				X	2017		X	0.2 metre	X	0.5 metre	X	4 days		black water , sewerage burst
86	X						X			X							X			
87		X				X		X				X								
88		X				X		X		X	2017		X				X			
89		X						X		X	1974 to 2017						X			
90	X					X				X	1974 , 1954- 2017			3.2 metre		3.2 metre				
91	X					X				X	2017				X	0.6 metre	X	2 days		
92	X					X						X							X	
93	X					X				X	2017 , 2016				X	1.4 metre	X	william St - 2 days		
94	X						X			X	2017				X	0.02 metre	X	For a couple of Days All side streets off commercial road		
95	X					X						X			X	20mm				
96	X					X						X								
97	X					X				X	twice 1989 5ft under house						X			
98	X	X				X				X	2012 , 2017								X	
99	X					X				X	flood since 2008								X	
100	X	X				X				X	2012 , 2013 , 2017		X	0.75			X	3 days		

#	Do you know if your house/business has a risk of being flooded (Tick one only)			Do you know if what size of flood your house/ business could be affected? (Tick one only)			How do you think you would respond to a major flood in this area (tick one only)					
	Yes, I know my house/ business could be flooded	Yes, I know my house/ business cannot be flooded	no, I don't know/ I'm not sure if my house/business could be flooded (go to question 7)	My house/business could be flooded 1n a so-called 1% AEP 1 in 100 year) flood	My house/business could be flooded in a so-called probable maximum flood	My house/business could be flooded but I'm not sure of the name of the flood	Evacuate early to an official evacuation centre in Murwillumbah	Evacuate else where	Remain at my house	Don't know/not sure	Other	please describe:
39		X							X			
40	X			X			X					
41			X	X					X			
42	X			X					X			
43	X					X				X		
44	X			X			X	X	X			
45	X					X			X			
46			X	X					X			our house is 2 storey we would stay upstairs
47	X				X			X				if I knew that leree would be breached
48	X			X				X				
49			X						X			
50		X							X			
51	X			X						X		
52	X					X			X			
53	X			X				X	X			
54	X			X					X			it's on a hill in town
55	X			X				X	X			
56	X				X				X			
57	X			X				X				
58			X					X				
59	X			X				X				
60	X			X						X		
61		X							X			
62			X						X			
63			X						X			
64			X	X								
65		X				X			X			
66	X			X			X					
67	X				X				X			
68			X						X			
69	X			X					X			
70			X					X				
71	X				X						X	
72		X			X			X				
73			X			X			X			
74		X		X					X			
75	X					X			X			
76	X			X				X				
77	X			X				X				
78			X	X				X				
79		X							X			
80			X							X		
81		X							X			
82			X						X			
83	X					X			X			
84	X				X		X					
85			X							X		
86			X	X			X		X			
87	X				X						X	
88	X					X		X				
89	X				X						X	
90	X									X		
91	X					X				X		
92		X				X			X			
93	X			X					X			
94			X						X			
95	X				X		X					
96		X							X			provide assistance
97	X			X						X		
98		X			X				X			
99	X				X			X				
100	X					X	X				X	

#	If you are likely to evacuate, what factors are most important to you (Please rank the following options from 1 to 5						If you are likely to remain at your house, what factors are most important to you (Please rank the following options from 1 to 5						
	Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for unin terrupted access to medical facilities	Safety of our family	not applicable (I intend to remain at my house)	Other	please describe:	Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for to care for animals	My house cannot be flooded and we can cope with isolation	Concern for security of my property if I exacute	not applicable (I intent to evacuate from my house)	Other	please describe:
39	1	2	3	4	5		1	5	2	3	4	6	
40	1 X	2	3	5	4		2 X	3	6	1	5	4	
41				X			1	2	4	3			
42	X												
43	2	3	1	4	5		3	2	6	1	4	5	
44	2	3	1	4		depending on depth	3	2	5	1	4	6	if instructed by SES
45							X	X					
46				X									none of the above
47							3	1		2			
48	X		X										
49				X			3	2	1	4			
50				X					X				
51	2	3	1	4			3	2	4	1			
52				X			2				6	1	
53				X					1				
54			X										
55				X						X			
56	1	2	3	4	5		2	3	4	1	5		
57	X						X						
58	3	2	1 X	4	5		2	1		3			
59	2	3	1 X										
60	1	3	1	?			5	1	6	1	?		
61							3		2	1			
62	2	3	1				2	1	3	4			
63				X					X				
64													
65				X					X				
66	2	4	1	5	3		3	4		2	1	5	
67							1	4	3	2			
68	4	3	5	1	2		2	6	1	3	4	5	
69				X				X					
70	2	3	1	4	5								
71	3	4	2		1		3	6	5	2	4	1	
72													
73				X			3	1	2	4	6	5	
74								X	X				
75	X						X	X					
76	2	3	1	4			2	1	4	3			
77													
78		X	X				X	X					
79				X					X	X			
80	2	3	1	4	5		3	2	5	1	4	6	
81				X					X				
82	1	1	2	3			1						
83				X			3	1	4	2	5	6	
84	2	3	1	4	5		2	5	4	3	1	6	
85			X					X					
86	2	3	1	5	4	able to contact to my family phone / wifi access etc.	2	3	1	4			
87													
88	3	2	1	5	4		3	4	6	2	1	5	
89					X							X	
90	X						1			2			
91	X									X		X	
92													
93													
94	4	2	1	3	5		2	1	4	3	6	5	
95	1	2	3	5							X		
96							6	2	1	3	4	5	
97													
98	3	4	1	2			3	4	1	2	5		
99			X				X						
100	1	3	2	5	4		1	3	6	2	4	5	

#	What type of property do you have? Residential	Commerical	Industrial	Vacant land	Other (please specify)	With respect to this property are you… The owner	The tenant	A business person	Other (please specify)	Have you Experinced Floods In this Area? Yes	Years	No
101	X					X				X		
102	X					X						
103	X					X				X	2017	
104	X					X				X	Mar-17	
105	X					X				X		
106	X					X						no
107	X					X				X	2017	
108	X						X			X	2017	
109					X				X	X	1978, 1979, 1988, 2017	
110	X					X				X		
111	X					X				X	1950s through 2017	
112	X					X				X	2017	
113	X					X				X	from 1979	
114	X					X				X	2016, 2014	
115		X				X						no
116				X		X						
117	X					X				X	all floods since 1999	
118	X					X				X	2017	
119	X					X				X	2017	

#	How did the biggest of these floods affect you? (tick all that apply) Water over main building	please describe depth:	Water in garage and sheds	please describe depth:	Lost access due to flooding of roads	please describe depth:	not applicable/ not affected	Other (please specify)	Do you know if your house/business has a risk of being flooded (Tick one only) Yes, I know my house/ business could be flooded	Yes, I know my house/ business cannot be flooded	no, I don't know/ I'm not sure if my house/business could be flooded (go to question 7)
101	X	1.12 metre 2 feet	X						X		
102											
103	X	3cm	X	1 metre	X	william St approx 24 hrs					X
104	X	2.5 metre			X						
105							X			X	
106									X		
107			X	1 inch	X	flooded out of murwillumbah All roads				X	
108			X	2m					X		
109	X	1.5m	X	7.5m	X	tunnel rd storers siding				X	
110	X		X		X	William St Murwillumbah				X	
111					X	Reynolds St 2 days approx					X
112			X	1m	X	charles at reynolds st			X		
113					X	main CBD	X		X		
114			X	1m					X		
115									X		
116											
117							X		X		
118					X	0.9m			X		
119			X	0.3m					X		

#	Do you know if what size of flood your house/ business could be affected? (Tick one only) My house/business could be flooded 1n a so-called 1% AEP 1 in 100 year) flood	My house/business could be flooded in a so-called probable maximum flood	My house/business could be flooded but I'm not sure of the name of the flood	How do you think you would respond to a major flood in this area (tick one only) Evacuate early to an official evacuation centre in Murwillumbah	Evacuate else where	Remain at my house	Don't know/not sure	Other	please describe:
101			X	X					
102						X			
103				X					
104	X	X				X			
105						X			
106	X					X			
107	X				X				
108		X		X					
109						X			
110	X					X			
111						X			
112			X				X		
113						X			
114					X				
115		X						X	Prepare business for flooding and move to a safe area
116									
117	X					X			
118	X					X			
119	X				X				

#	If you are likely to evacuate, what factors are most important to you (Please rank the following options from 1 to 5 Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for unin terrupted access to medical facilities	Safety of our family	not applicable (I intend to remain at my house)	Other	please describe:	If you are likely to remain at your house, what factors are most important to you (Please rank the following options from 1 to 5 Discomfort/ inconvenience/ cost of being isolated by floodwater	Need for to care for animals	My house cannot be flooded and we can cope with isolation	Concern for security of my property if I exacuate	not applicable (I intent to evacuate from my house)	Other	please describe:
101	2	3	1				1	3	5	2	4		
102				X									
103	X						X						
104			X				X			X			
105									X				
106	3	2	1	4	5		1	3	4	2	5		
107	3	5	2	4	1	loss of access to work	3	5	2	4	1		
108	2	3	1	4	5		1	2	4	3	5	6	
109									X				
110				X					X				
111							2			1			
112			1				2	1					
113			1							1			
114	1	2	3										
115		1	2				3		2	1			
116													
117							2		1	3			
118							1						
119	4	2	1				3	2	5	1			

Table J2 - Response to Flood Risk Management Options

#	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?											Do you have any other suggestions for reducing flooding problems than those listed above? Please describe.
	Flood modification options: Options aimed at modifying the way floodwaters move, thereby reducing the extent, depth and velocity of floodwater.						Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or		Response modification options: Are options aimed at improving the way emergency services and the general public responds before, during and			
	Increase height of East Murwillumbah and Commercial Road levees	Upgrade of existing CBD levee pump systems and installation of new pumps behind East Murwillumbah and Dorothy StreeUBrothers levees	New pump system in Proudfoots Lane	Regrading of Williams Street (near Dorothy Street) and near the intersection of Commercial Road/Wharf Street to drain water away from existing residential and commercial properties	Stormwater upgrades in Proudfoot Lane, Nullum Lane and William Street	Re-design of Commercial Road levee gates to allow gates to open and release water trapped behind the levee as flood recedes	Modifications to Council's planning documents to reduce population intensification in high-risk areas	Temporary flood barriers to prevent ingress of floodwaters into commercial properties	Updates to SES Local Flood Plan	Real-time flood gauging and warning system	Community education programs	
1	unsure	unsure	unsure	unsure	unsure	unsure	unsure	unsure	unsure	unsure	unsure	Unsure about the aboe Suggestions.i don't feel that increasing the height of levees would be benefical to sububs down stream.
2		strongly support	strongly support	strongly support	support	strongly support	support	support	support	strongly support	support	
3	AGAINST	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	support	strongly support	support	We did not flood from river flood water-we actually flooded from backed up storm water that could not escapre into.myall creek from the nthn end of tumbulgum road houses from behind country energy.at the top of the 2017 flood the water came to within 5 of a meter from the top fo the levy behind out house at this time it had also gone over t/valley way across the river.
4	NEUTRAL	support		support	support	support	support	support	support	support	support	
5	unsure	support	unsure	strongly support	strongly support	strongly support	support	support	strongly support	strongly support	support	
6	support	support	support	support	support	support	support	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL	
7	support	strongly support	support	support	support	support	support	support	support	support	support	Real time notitications of road closures tweed valley wat,clothes ck,tumbugum and alternative routes avilable.across,information through a quick link or a app for those of route during day times.
8	AGAINST	strongly support	support	support	support	strongly support	support	support	support	support	support	I believe tweed river needs some rubish(tree,mud)learned out of it,maybe dredgeng in places.
9	support	support	support	support	support	support		support	support	support	support	
10	AGAINST	strongly support	strongly support	strongly support	NEUTRAL	support	support	AGAINST	support	strongly support	strongly support	
11	AGAINST	strongly support	unsure	unsure	unsure	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	SMS is a good way to rounde very localized and on deme infrmara,unfortunatly in the recent flood the way was not accurate and ofren not alreted
12	strongly support	strongly support	strongly support	strongly support	strongly support	AGAINST	strongly support	support	strongly support	support	NEUTRAL	its good to see that nothing is suggested for south muh'bah ,will it continue as the sorry poor bugger you"area.somthing should be done in the area or ave we just medicare and its just too hard.
13	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	strongly support	strongly support	strongly support	Concerns ie increased hight to commercial rd levee would push morg water into.bray pk as did last flood.more wastte would protect town if increased.
14	support	strongly support	strongly support	strongly support	strongly support	strongly support	AGAINST	support	strongly support	strongly support	strongly support	I was evawated to chruch hail rain st and altough everyone was trying their best,they were well equiped to deal with the arvial of many people.commercial should support water entries by ensuring the supply of needed items.
15	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
16	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	unsure	strongly support	strongly support	strongly support	strongly support	
17	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
18	support	support	support	support	support	support	support	support	support	support	support	
19	unsure	unsure	unsure	unsure	unsure	unsure	support	unsure	strongly support	strongly support	strongly support	
20	NEUTRAL	support	NEUTRAL	support	support	NEUTRAL	support	NEUTRAL	support	support	support	I was all for the second dam for our river.i still thing that two dams could helo reduce the flooding of murwillumbah.the blow out at green hills happens in the 1974 flood a lot of people aid that when that happened the flood height leveled out.i think that it helped save the cbd when this happened in the last flood so why not leave it so the water can go out on the flood planks.
21	unsure	support	strongly support	support	support	support	strongly support	support	support	support	support	Regylar flood updates on radio ses massges to modles end clear commuincates at all times.
22	support	support	support	support	support	support	support	support	support	support	support	
23	unsure	strongly support	strongly support	strongly support	strongly support	unsure	support	support	strongly support	strongly support	support	Don't build houses on flood plains,ship clearing so much land as tree hold the soil together.put nerb & gutter in dorothy street & in okas affected shreet so flood properly diver way garden then under the house.house close to the river should not be built below a minimum height.
24	strongly support	strongly support	strongly support	strongly support	strongly support	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	
25	AGAINST	support	support	AGAINST	support	AGAINST	strongly support	support	support	support	support	what thing can we put in place to protect south Murwillumbah rather then protect the CBD further
26	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	strongly support	strongly support	strongly support	strongly support	
27	support	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL	support	support	strongly support	support	NEUTRAL	Dredge the river south of the Bridge

#	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?											Do you have any other suggestions for reducing flooding problems than those listed above? Please describe.
	Flood modification options: Options aimed at modifying the way floodwaters move, thereby reducing the extent, depth and velocity of floodwater.						Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or		Response modification options: Are options aimed at improving the way emergency services and the general public responds before, during and			
	Increase height of East Murwillumbah and Commercial Road levees	Upgrade of existing CBD levee pump systems and installation of new pumps behind East Murwillumbah and Dorothy StreeUBrothers levees	New pump system in Proudfoots Lane	Regrading of Williams Street (near Dorothy Street) and near the intersection of Commercial Road/Wharf Street to drain water away from existing residential and commercial properties	Stormwater upgrades in Proudfoot Lane, Nullum Lane and William Street	Re-design of Commercial Road levee gates to allow gates to open and release water trapped behind the levee as flood recedes	Modifications to Council's planning documents to reduce population intensification in high-risk areas	Temporary flood barriers to prevent ingress of floodwaters into commercial properties	Updates to SES Local Flood Plan	Real-time flood gauging and warning system	Community education programs	
28	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	strongly support	strongly support	strongly support	support	Dredge the tweed river of all the silt to allow for better flow especially in time of flood. Increase height of tweed valley way (or other roads) to allow for access in / out of mur-bah. In 2017 flood all entries/exits were blocked / washed out & left mur-bah standard.
29	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	support	strongly support	support	needs pump in east Murwillumbah lots of flooding if pump was put in most water wood be kept out flood wrtef is backup water
30	support	strongly support	unsure	unsure	unsure	support	unsure	unsure	strongly support	strongly support	unsure	in a letter to the general manager on the 6-6-2016 I states may concern for the flooding of east Mur-bah never recored a reply. During the 2017 flood rang S.E.S to obtain tweed river heights an d was told to ring weather bureau river heigly were seldom gien over the A.B.C give bak the reading of river heightsto our local S.E.S.
31	support	support	support	support	support	support	support	support	strongly support	strongly support	support	the flood water In east murwillumbah was not effected but storm water backup was the main isuse . If pumps was installed at accores St culverts it would cmerate less damage to property caused by storm water backup .not flood water flood water only sumped the leavey at murwillumbah easr school for short period and the damage was already done
32	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
33	unsure	support	support	support	support	support	support	NEUTRAL	support	support	support	
34	support	strongly support			strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	I think the levee's have lulled people into a false sence of security thus they have built out undrer their home s which were on stumps. Alsowith the strong deluge of rain inside the levee there is nowhere for the water to get out.there was a lot of flash flooding &sewerage breakdown , i used to live in lismore region they have all built out under their home too , at great loss,this tme round ,flats for uni student etc. they used to be so prepared for a flood , regularly moving goods ready
35	strongly support	strongly support	support	support	support	support	Neutral	support	support	strongly support	support	Real time flood gaugring to the avilable on the internet with data points updating historcal events.therefore pmp lable rave been enrolled(on second thoguths perpahps not pmp since these are likely to scare the pants off some and may affect real estate valuations.
36	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
37	strongly support	strongly support	strongly support	Neutral	Neutral	strongly support	strongly support	Neutral	support	support	Neutral	in 3 previous flooding events the pumps at harhgan st commercial road failed on two occasions thoer cantinved operations would have potentailly prevented water in updating under over house the last flood event would have benefical us hughely if the flood gets had been oferred once water had recoreded sufficiently
38	Unsure	Unsure	Unsure	Unsure	Unsure	Unsure	strongly support	Unsure	Unsure	Unsure	Unsure	
39	strongly support	strongly support	strongly support	strongly support	Unsure	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
40	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
41	strongly support	strongly support	Neutral	strongly support	strongly support	strongly support	Neutral	Neutral	strongly support	strongly support	support	Every warning sysyem to be done in ample time to leave if desued.
42	support	support	support	support	support	support	support		support	support		go back to radio im.fo eg river heights on UKI Tyacdm chillingam etc.raining,no rain steady we recevied all this before not now
43	strongly support	strongly support	support	support	strongly support	strongly support	Neutral	Neutral	support	strongly support	Neutral	Remoual of the pond in knox park or upgrade drainage sysyem so water don't flood nullm street.
44	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
45	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	Neutral	strongly support	strongly support	strongly support	support	
46	support	strongly support	support	support	Neutral	support	support	support	support	strongly support	support	
47	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	Create area for the water to go.this may include large area sunken for water these area could be used as palying fields + recreations area at time where there is no flooding-m flood area must +m homes + build home that adjust to flood
48	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
49	unsure	strongly support	unsure	strongly support	strongly support	support	strongly support	strongly support	strongly support	strongly support	strongly support	
50	support	support	support	support	support	support	support	support	support	strongly support	support	
51	Neutral	support	Neutral	Neutral	support	Against	support	support	support	support	support	
52	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	Neutral	support	strongly support	Neutral	I lived at the lowest point of Tumbulgum road behind the levee.my house collects the stomwater runoff of properties as far up as tumbulgum road.i have invested in a pume and
53	strongly support	strongly support	strongly support	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
54												I can not comment on which improvement to make.surely it's beyond my scope however you had quailfied water mangment advise & studies dual.the prble cannot make an informed decision like this no quote no feasibiln known.

#	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?											Do you have any other suggestions for reducing flooding problems than those listed above? Please describe.
	Flood modification options: Options aimed at modifying the way floodwaters move, thereby reducing the extent, depth and velocity of floodwater.						Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or		Response modification options: Are options aimed at improving the way emergency services and the general public responds before, during and			
	Increase height of East Murwillumbah and Commercial Road levees	Upgrade of existing CBD levee pump systems and installation of new pumps behind East Murwillumbah and Dorothy StreeUBrothers levees	New pump system in Proudfoots Lane	Regrading of Williams Street (near Dorothy Street) and near the intersection of Commercial Road/Wharf Street to drain water away from existing residential and commercial properties	Stormwater upgrades in Proudfoot Lane, Nullum Lane and William Street	Re-design of Commercial Road levee gates to allow gates to open and release water trapped behind the levee as flood recedes	Modifications to Council's planning documents to reduce population intensification in high-risk areas	Temporary flood barriers to prevent ingress of floodwaters into commercial properties	Updates to SES Local Flood Plan	Real-time flood gauging and warning system	Community education programs	
55	strongly support	strongly support	strongly support	unsure	unsure	strongly support	support	strongly support	strongly support	strongly support	support	Build a new dam at byrill creek to help regulate the water flow into the tweed river during flood times & release water,in advance of predicated heavy rainfall from clarrfy hall dam.in summary better man alements of exisiting furue water mangment infrastructure
56	AGAINST	strongly support	support	support	support	strongly support	strongly support	support	strongly support	strongly support	strongly support	
57	strongly support	strongly support	strongly support	strongly support	strongly support	unsure	unsure	strongly support	strongly support	strongly support	strongly support	Curb + Gutters for harwood st as only one side of street has them
58	support	support	strongly support	support	strongly support	support	support	support	strongly support	strongly support	support	
59	unsure	support	unsure	strongly support	strongly support	unsure	Neutral	Neutral	strongly support	strongly support	strongly support	Increaes the height of the dorothy st/brothrs levee at this had not overtopped we would not have flooded in the 2017 flood.
60	strongly support	strongly support	unsure	support	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	unsure	where we are we get inudated with water from the lack paddock as the pipes are usually blodked parallel to reynolds running under george street s.so there is back up this happens a lot!!
61	Neutral	support	support		support	support	support	support	support	support	support	
62	strongly AGAINST	strongly support	strongly support	support	strongly support	strongly AGAINST	strongly support	strongly AGAINST	support	support	Neutral	make commercial road one -way with tree islands so traffic cannot drive up &down in flood water which then is displaced by cars etc &enters our property by the wash.
63	unsure	strongly support	support	strongly support	strongly support	unsure	unsure	support	support	support	support	
64												
65	Neutral	support	support	support	support	support	Neutral	support	strongly support	strongly support	strongly support	I suffer an increase in the authority and input of local ses and increase local communication of conditions.
66	unsure	support	support	support	support	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	
67		strongly support	strongly support	Neutral	strongly support	strongly support	support	strongly support	strongly support	strongly support		Council should be aware of second wabe of debbie coming and prepare (insteaed of leaveing depot etc to flood_we all knew at 4 pm that we were in the eye of storm.
68	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	unsure	unsure	unsure	
69	Neutral	strongly AGAINST	strongly AGAINST	unsure	strongly AGAINST	strongly AGAINST	support	support	support	strongly support	support	I think for the people living in south side a street support is needed.they sufferd the worse in last flood.we were lucku in easy mu;bah due to levy walk but new families movding into the area neeed to be awore so they do not become blasé.people need to still reside they live in a flodd zone even with a levy walk.
70	strongly support	support	support	support	support	support	Neutral	support		strongly support	support	
71	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support		
72												instalk pumps @ for end of tumbulgum rd near properties 61,59,57 and 55 Tumbulgum Rd.
73	unsure	Neutral	unsure	support	support	support	support	support	unsure	unsure	unsure	Not really I moved to m"bah in dec 16 moving out council dead an analzing job undee very challenging circumstances.
74	strongly AGAINST	support	support	support	strongly support	support	support	support	support	support	support	
75	strongly support	strongly support	strongly support	Neutral	strongly support	strongly support	support	support	strongly support	strongly support	strongly support	Early flood warninfs & updates to area affected should be broadcase on radio have local radio active 24 hrs a day untill event is over if power is out most household have battery radios
76	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
77	Against	support	strongly support	strongly support	strongly support	strongly support	Neutral	support	support	support	support	
78	support	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	support	support	Neutral	
79	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
80	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	strongly support	strongly support	strongly support	strongly support	
81												
82	Neutral	Neutral	Neutral	strongly support	Neutral	Neutral	Neutral	Neutral	Neutral	support	support	
83	strongly support	strongly support		support		strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	
84	strongly support	strongly support	strongly support	strongly support	strongly support	Neutral	Against	support	support	strongly support	support	Would like to see the wall from the high school to commercail rd extended to same height as the main levee wahh! Ps please check the height of the trees on the river bank from boat ramp to the bridge
85	strongly support	strongly support	strongly support	strongly support	strongly support	Neutral	support	strongly support	strongly support	strongly support	support	Check easements are clear to assist re-directing water
86	support	support	support	support	support	support	unsure	unsure	strongly support	strongly support	strongly support	I recevied sms alart to evacuate at midnight and I read it next morning it was too late many resident in mumillnuhmh did;nt know that flood water goeas to their house.they did'nt prepare for anything to evacuate the council sohuld alart and infrom them before too late by radio or tb or text earlier.
87	support	support	support	support	support	strongly support	support	support	support	strongly support	support	
88	Neutral	strongly support	strongly support	strongly support	strongly support	support	support	strongly support	support	strongly support	support	
89	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	support	strongly support	strongly support	strongly support	strongly support	
90	support	Neutral	support	Neutral	Neutral	strongly support	unsure	Against	support	strongly support	support	Need a council worker or other traned to re set lavenoer creek pumps.pumps could not be truned/rest because council worker does not livew town.what about se traine up.

#	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.						Property modification options: Refers to planning controls and property modifications that reduce the potential for flooding or		Response modification options: Are options aimed at improving the way emergency services and the general public responds before, during and			
	Increase height of East Murwillumbah and Commercial Road levees	Upgrade of existing CBD levee pump systems and installation of new pumps behind East Murwillumbah and Dorothy StreeUBrothers levees	New pump system in Proudfoots Lane	Regrading of Williams Street (near Dorothy Street) and near the intersection of Commercial Road/Wharf Street to drain water away from existing residential and commercial properties	Stormwater upgrades in Proudfoot Lane, Nullum Lane and William Street	Re-design of Commercial Road levee gates to allow gates to open and release water trapped behind the levee as flood recedes	Modifications to Council's planning documents to reduce population intensification in high-risk areas	Temporary flood barriers to prevent ingress of floodwaters into commercial properties	Updates to SES Local Flood Plan	Real-time flood gauging and warning system	Community education programs	Do you have any other suggestions for reducing flooding problems than those listed above? Please describe.
91	strongly support	strongly support	Neutral	strongly support		support	Neutral	Neutral	support	strongly support	support	Stop raising sports ground(i.e Hockey fields) which send water back into Nallum brisbane st better drains and reguler maintence as this area floods in heavy rain on a very regular basis.
92												
93	Neutral	strongly support	support	strongly support	strongly support	support	strongly support	support	strongly support	strongly support	strongly support	
94	strongly support	strongly support	strongly support	strongly support	strongly support	Against	strongly support	strongly support	strongly support	strongly support	strongly support	
95	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	Neutral	strongly support	strongly support	strongly support	strongly support	
96	support	strongly support	strongly support	support	support	support	strongly support		strongly support	strongly support	strongly support	increase depth of know park pond for greater catchment from nullum st nullum lane.increase depth of cane drains east murbh to condong should ground to river with deiversion baffles,create diversion channels at peak flow points to reduce water velocity
97	strongly support	strongly support	strongly support	support	support	support	support	support	strongly support	strongly support	support	
98	strongly AGAINST	Neutral	strongly support	Neutral	Neutral	strongly support	Against	Neutral	support	strongly support	Neutral	
99	strongly support	strongly support	strongly support	strongly support	strongly support		strongly support	unsure	unsure	strongly support	strongly support	
100	strongly support	support	unsure	support	support	strongly support	unsure	strongly support	support	strongly support	support	
101	Against	strongly support	support	support		support	strongly support	support	strongly support	strongly support	strongly support	againist raising the levee on town side as this would put more water on the south side where so many people where so badly inpacked this time inclding my olderly parents water from gutter runs up drive way and down under our house and into next door maybe more storm water drains along street would help.
102												
103	unsure	strongly support	unsure	strongly support	strongly support	strongly support	strongly support	unsure	strongly support	strongly support	strongly support	Updated texts from SES would have beem appreciated and recevied at aprox 4 am 1/4/17 and I lost my car in the process.if I had receveid updated ses text alert I would have drain it up the hill to high ground
104	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support		Council clean levee + creek leading to thomes stop bulding in flood areas.im still waiting for council to address sink haes +broken storm water drains in my back yard-your are shocking.
105	support	support	support		support		Against	Neutral	strongly support	strongly support	strongly support	Dredge the river + creek silting is a large problem
106	Neutral	support		support	strongly support	support	neutral	strongly support	strongly support	strongly support	neutral	inform new residents of flooding problems
107	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	neutral	strongly support	strongly support	support	
108	strongly support	strongly support	support	strongly support	support	support	support	support	support	support	support	
109	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	better communication
110				strongly support		strongly support						
111	unsure	strongly support	strongly support	strongly support	strongly support	strongly support	support	support	strongly support	strongly support	strongly support	Clearly a better local radio flood info
112	support	strongly support	strongly support	support	support	support	support	support	support	support	support	Regular cleaning and maintance of stormwater drains
113	support	unsure	support	support	support	neutral	against	neutral	support		support	make alternative route for water
114	strongly support	strongly support	strongly support	support	strongly support	strongly support	unsure	neutral	support	strongly support	support	Stand by power for flood pumps as cyclones could cause power outages at a time of strong flooding. Authorised persons in immediate vicinity of pumps to monitor and assist in removal of detritus etc during food events.
115	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	strongly support	Reliable and accurate real time Facebook readings and reports rather than relying on Facebook community pages for information that is unreliable and may be false
116												
117	neutral	neutral	neutral	neutral	neutral	support	neutral	support	support	support	support	
118	unsure	unsure	unsure	unsure	unsure	unsure	unsure	unsure	strongly support	support	unsure	
119	support	support	support	support	support	support	support	support	support	support	support	

APPENDIX K

STAGE HYDROGRAPHS

TWEED SHIRE COUNCIL

LEGEND

● Location of Stage Hydrograph

Notes:

Aerial photograph date: 2015

N W E S

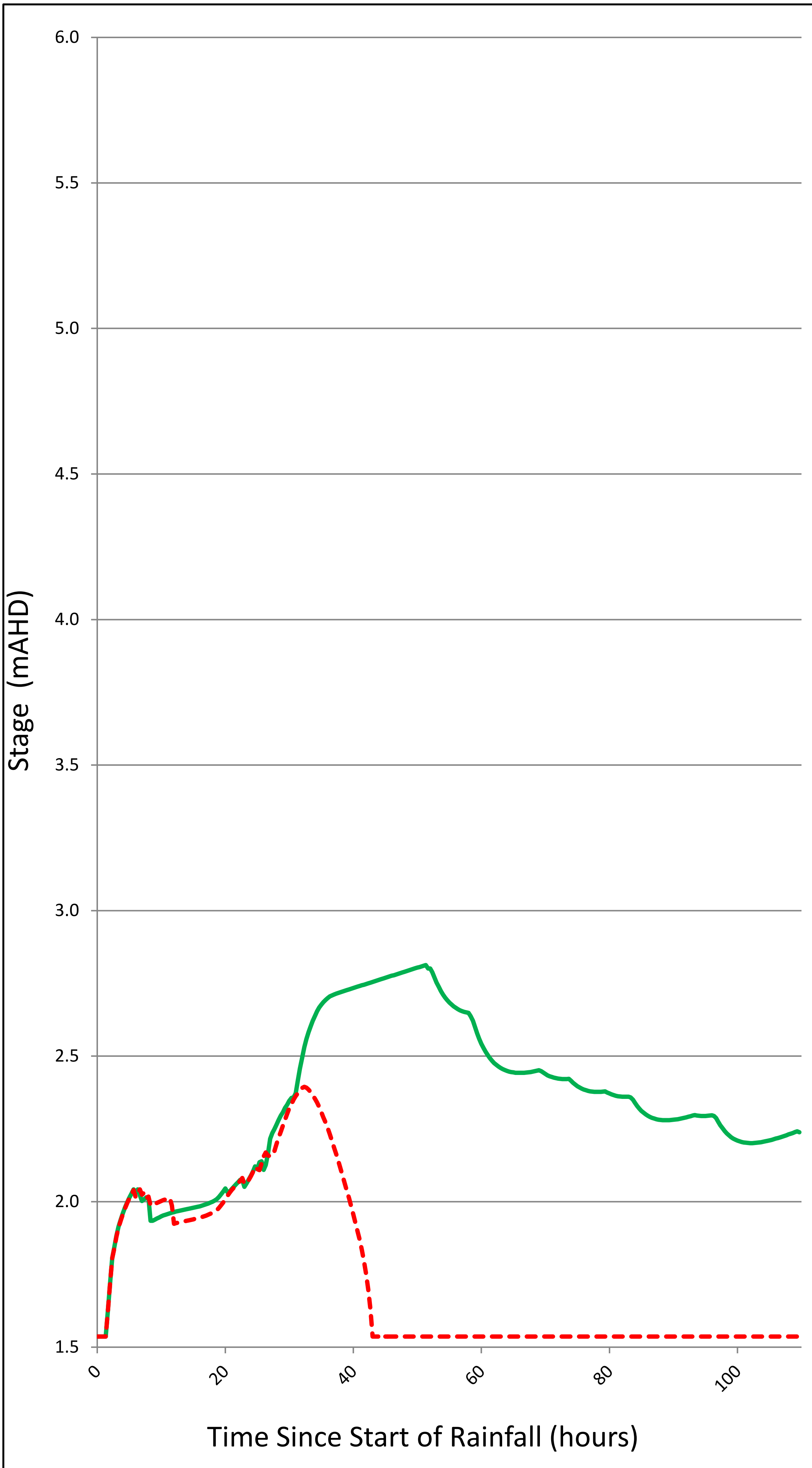
0 0.25 0.5 Km

Figure K: Stage Hydrograph Extraction Locations

Prepared By:

Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW 2000

File Name: Stage Hydrograph locations.wor



TWEED SHIRE COUNCIL

LEGEND:

20%AEP Existing Stage Hydrograph

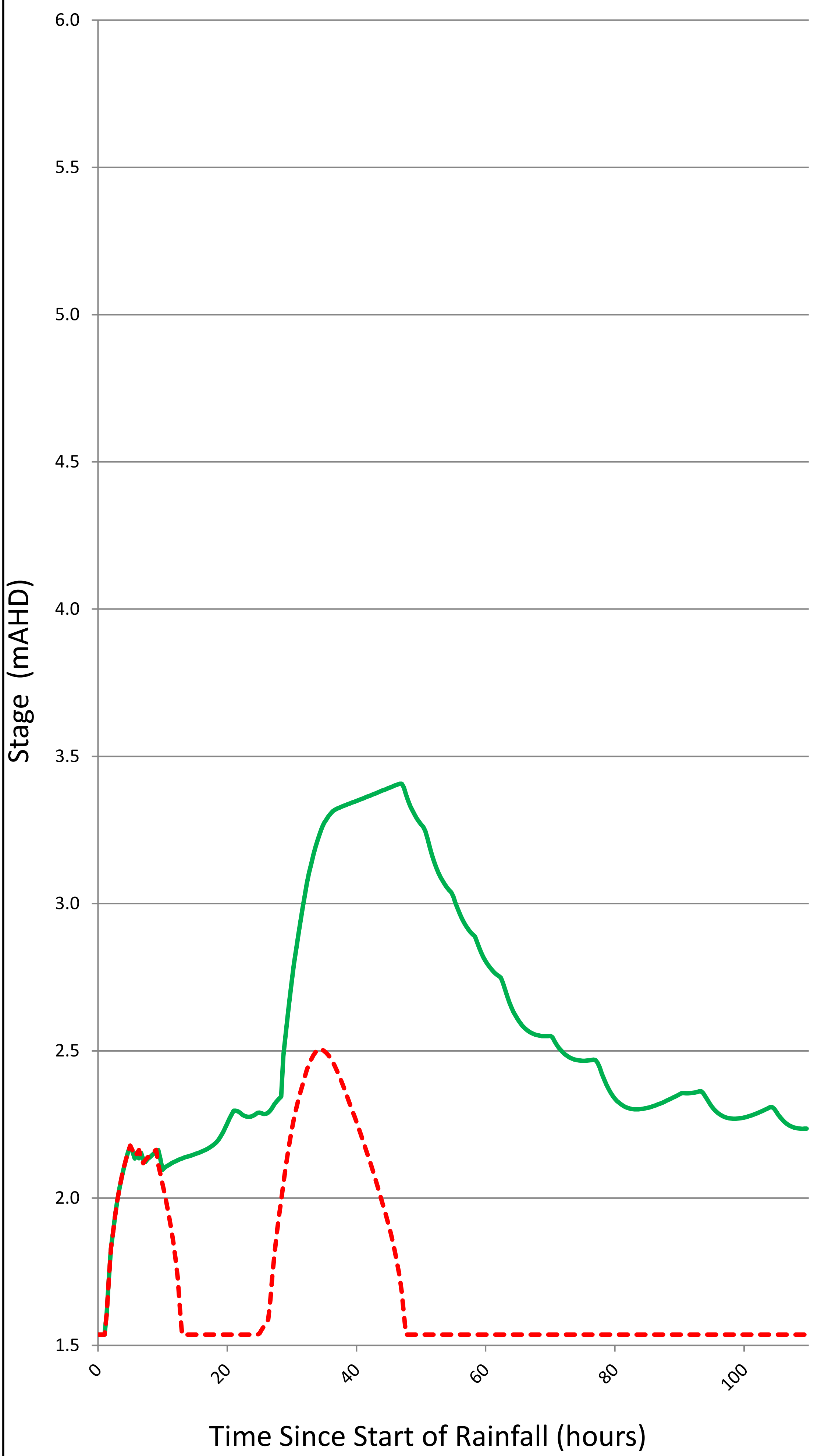
20%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K1.1: 20%AEP Stage Hydrograph Comparison behind Dorothy St Levee

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

5%AEP Existing Stage Hydrograph

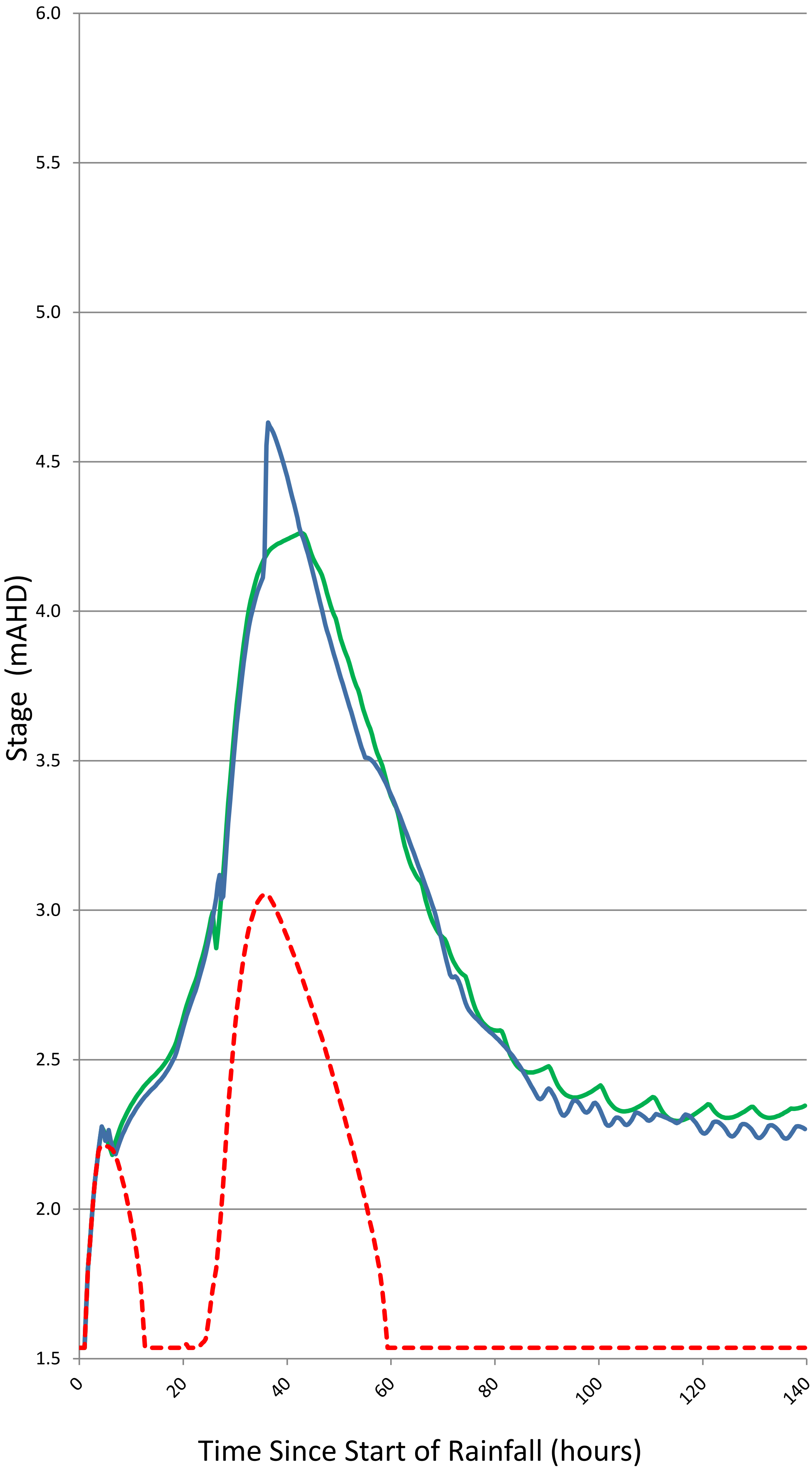
5%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K1.2: 5%AEP Stage Hydrograph Comparison behind Dorothy St Levee

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

1%AEP Existing Stage Hydrograph

1%AEP Levee Breach Stage Hydrograph

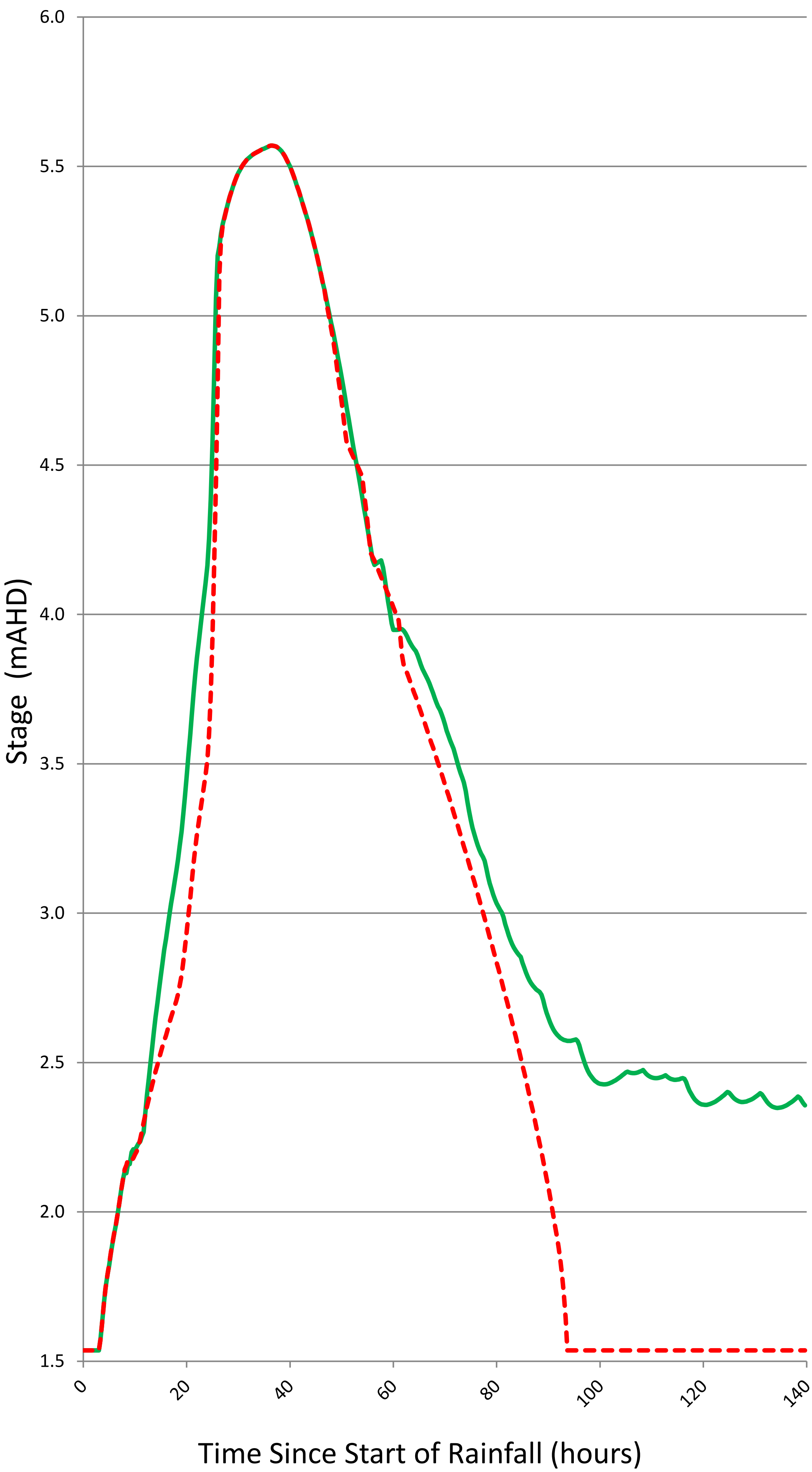
1%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K1.3: 1%AEP Stage Hydrograph Comparison behind Dorothy St Levee

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

0.2%AEP Existing Stage Hydrograph

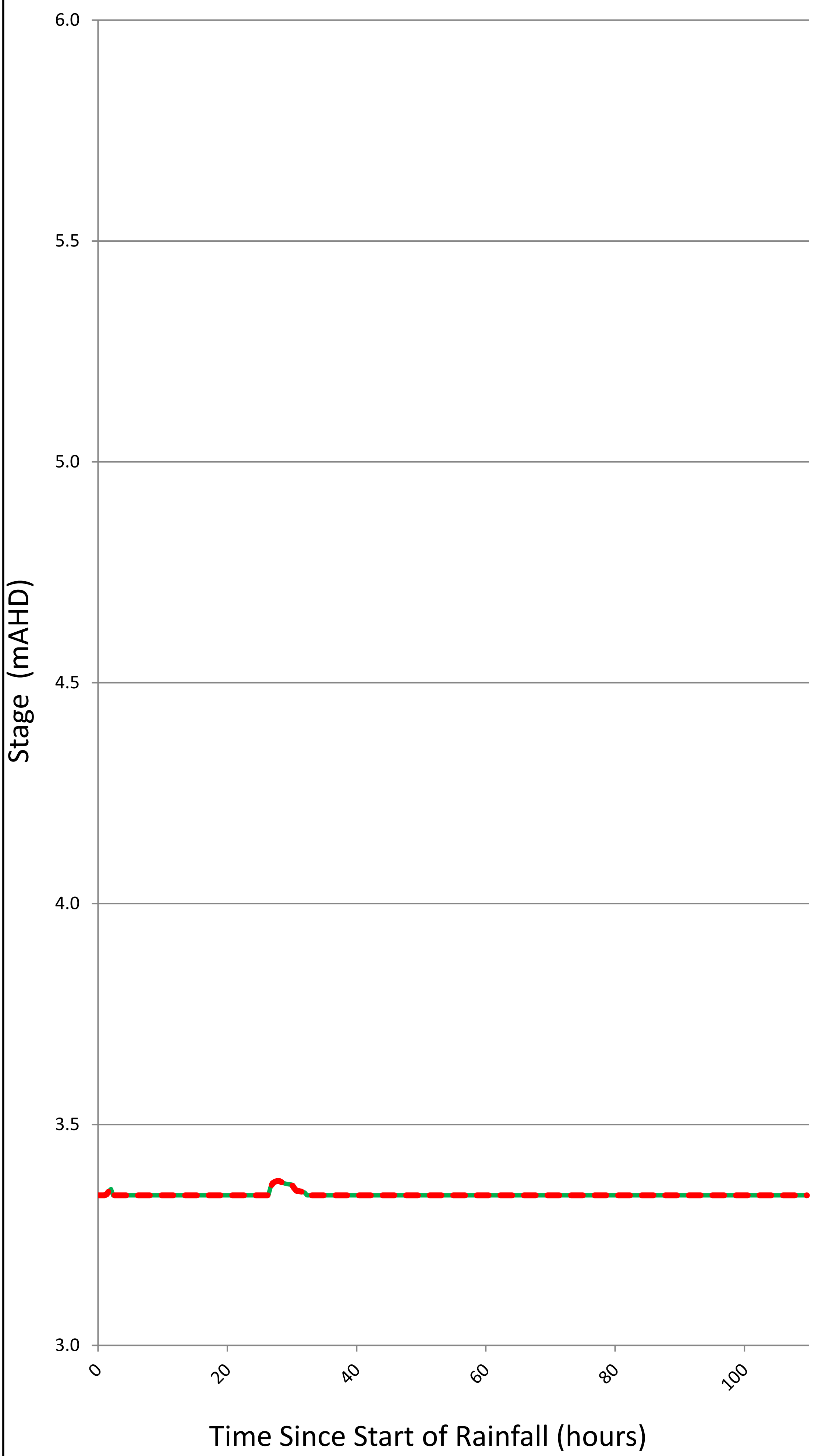
0.2%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K1.4: 0.2%AEP Stage Hydrograph Comparison behind Dorothy St Levee

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



LEGEND:

20%AEP Existing Stage Hydrograph

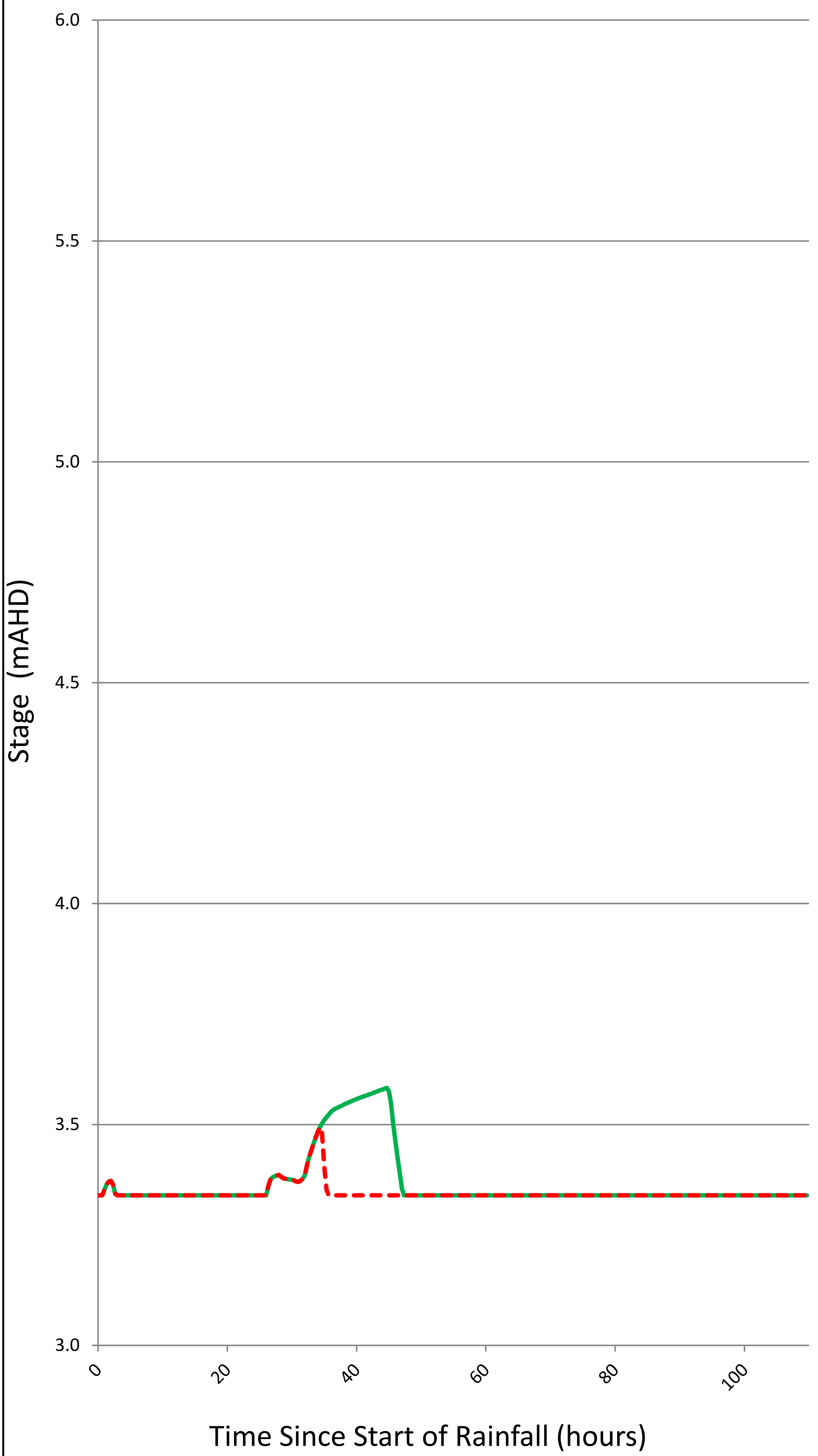
20%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K2.1: 20%AEP Stage Hydrograph Comparison in East Murwillumbah

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

5%AEP Existing Stage Hydrograph

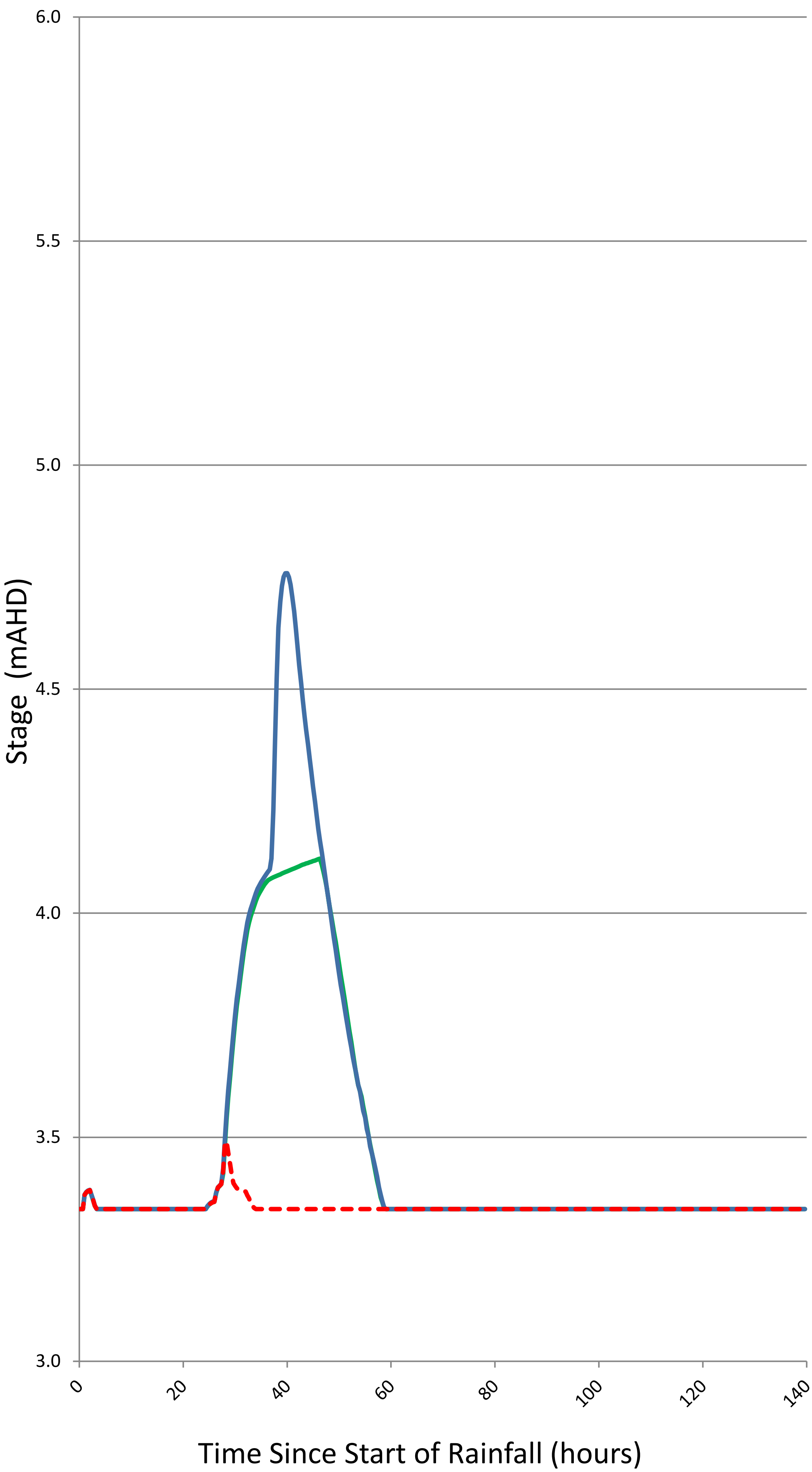
5%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K2.2: 5%AEP Stage Hydrograph Comparison in East Murwillumbah

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

- 1%AEP Existing Stage Hydrograph
- 1%AEP Levee Breach Stage Hydrograph
- 1%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K2.3: 1%AEP Stage Hydrograph Comparison in East Murwillumbah

Prepared By:
Catchment Simulation Solutions
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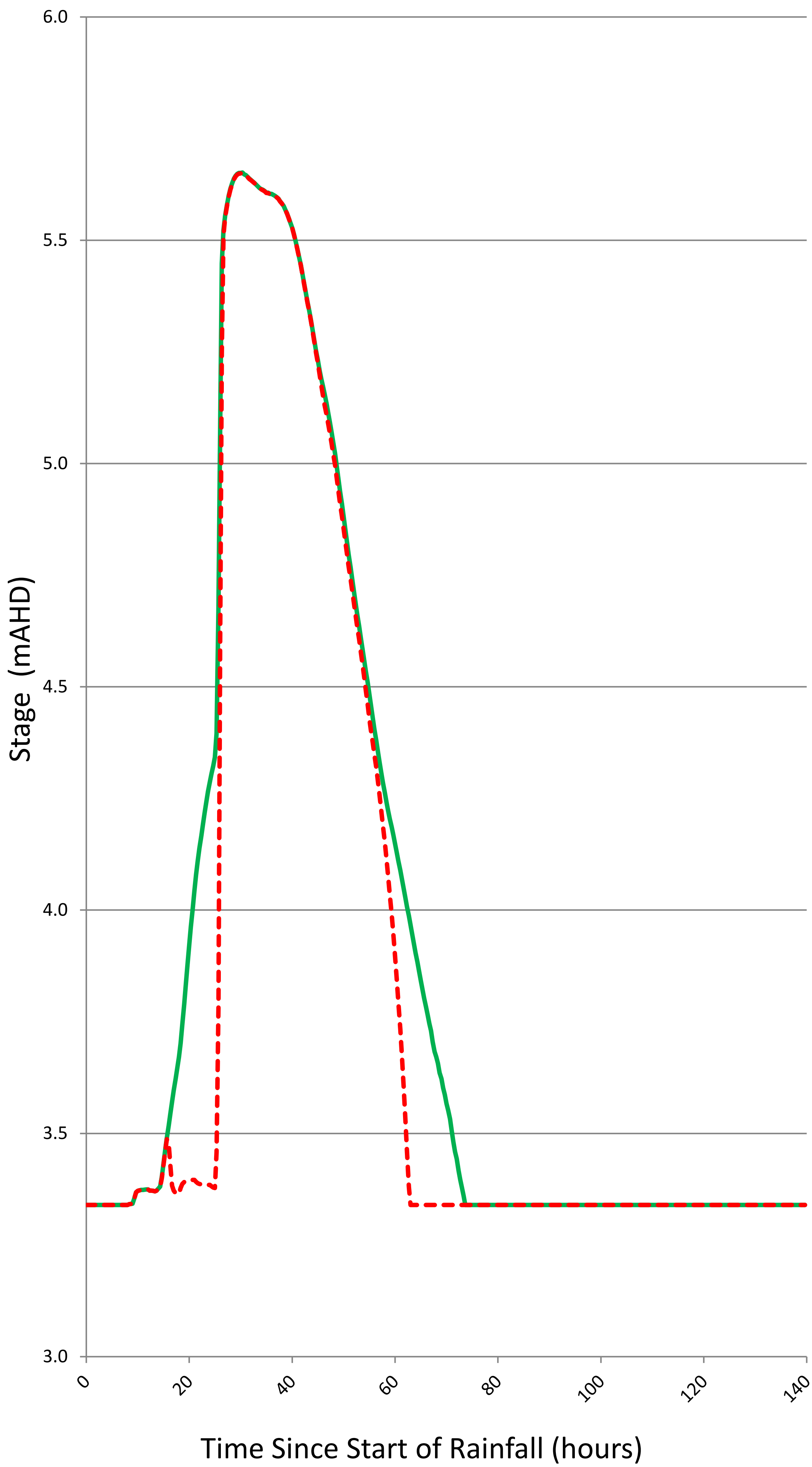
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

0.2%AEP Existing Stage Hydrograph

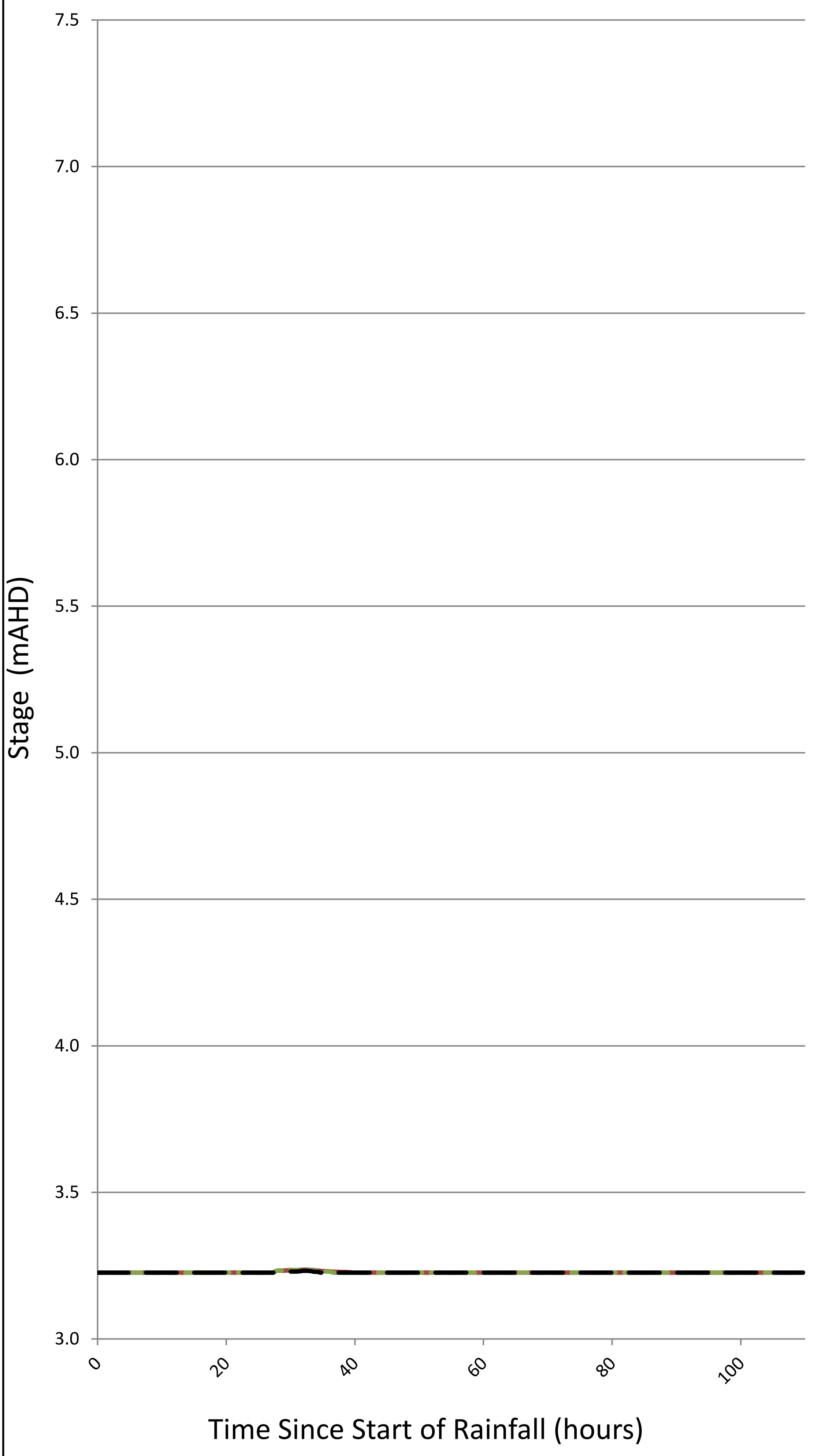
0.2%AEP Pump Upgrade Stage Hydrograph

Notes:

Figure K2.4: 0.2%AEP Stage Hydrograph Comparison in East Murwillumbah

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

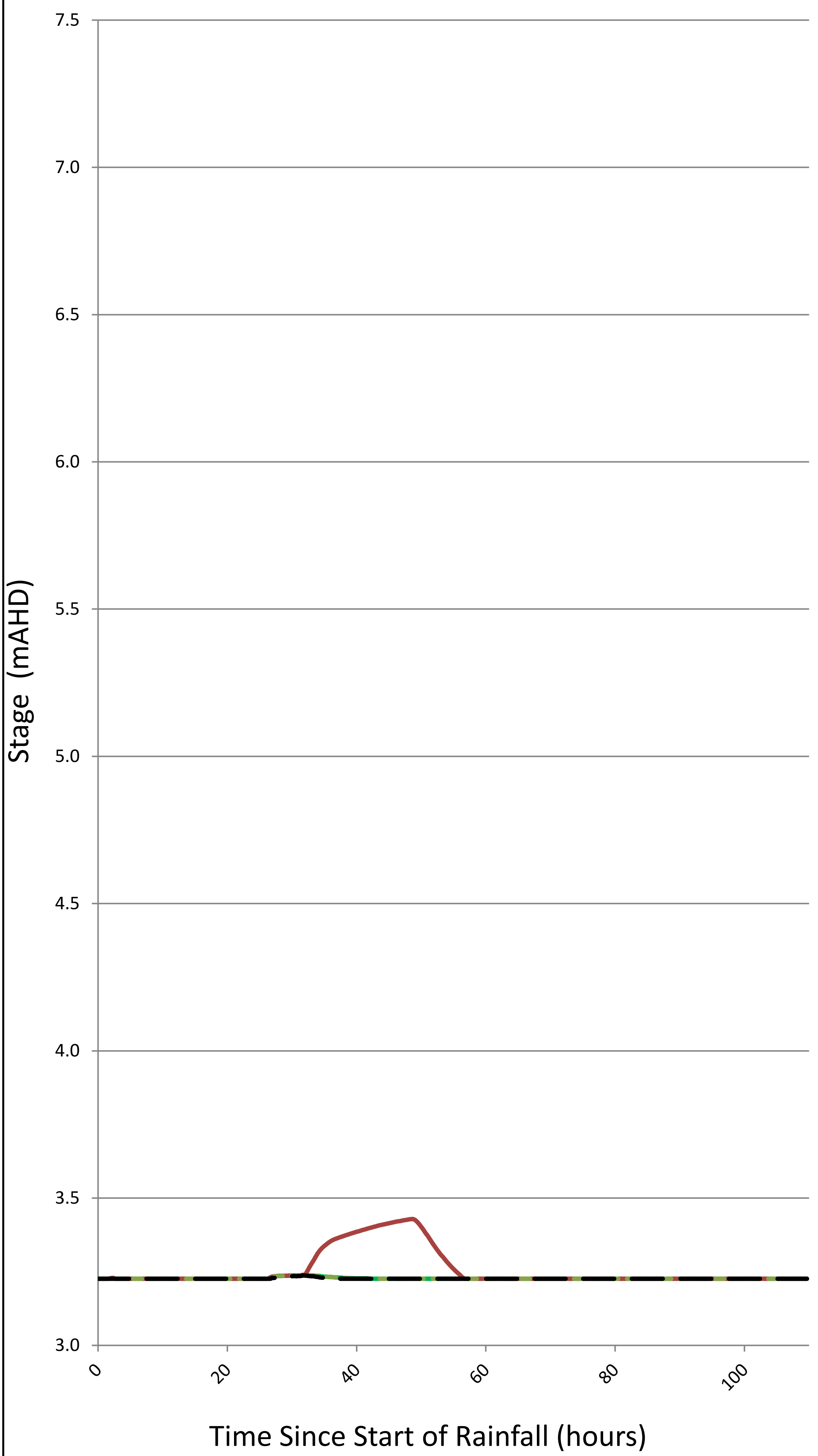
- 20%AEP Existing Stage Hydrograph
- 20%AEP Pump Failure Stage Hydrograph
- 20%AEP Pump Upgrade Stage Hydrograph
- 20%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K3.1: 20%AEP Stage Hydrograph Comparison on Wollumbin St at Knox Park

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

5%AEP Existing Stage Hydrograph

5%AEP Pump Failure Stage Hydrograph

5%AEP Pump Upgrade Stage Hydrograph

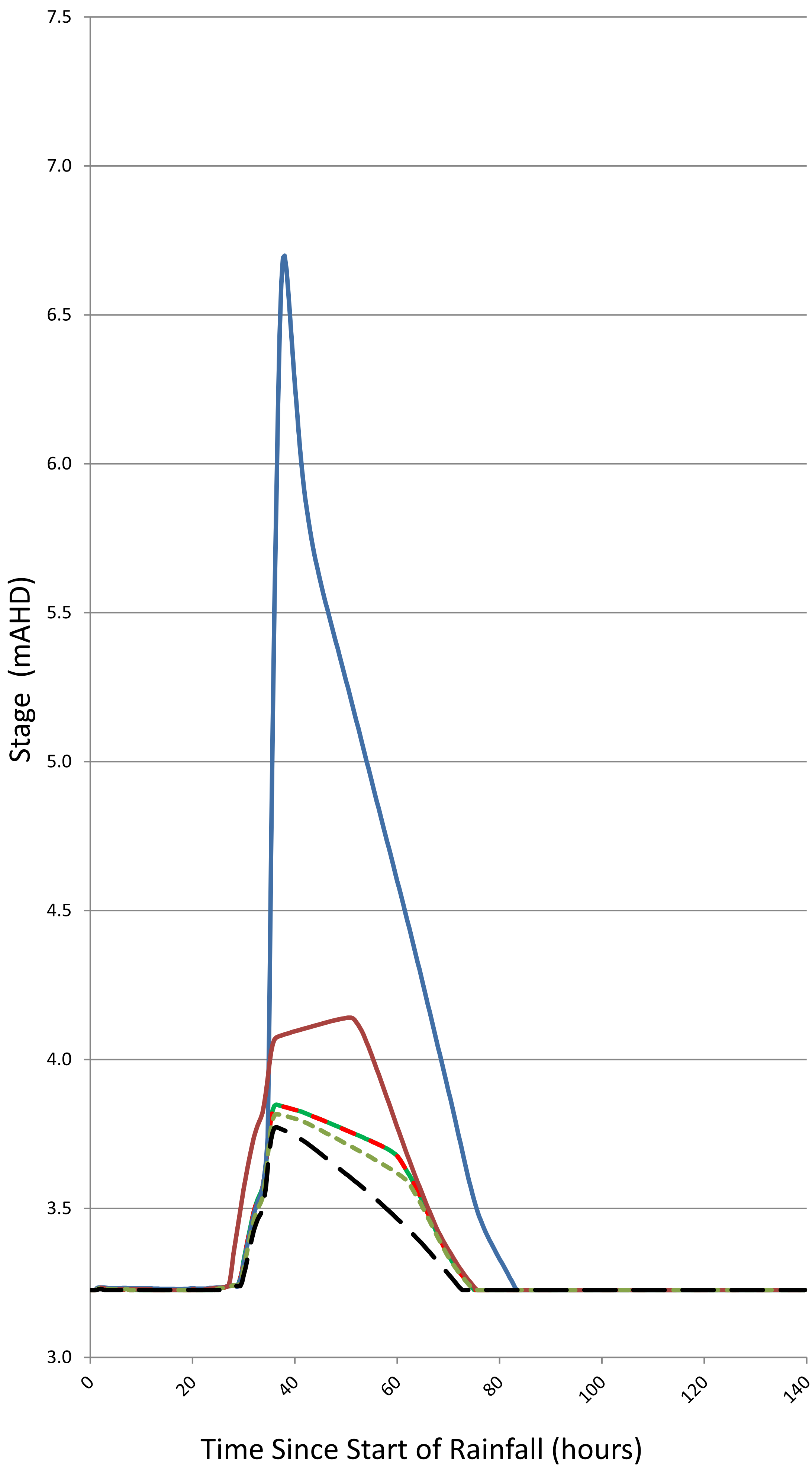
5%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K3.2: 5%AEP Stage Hydrograph Comparison on Wollumbin St at Knox Park

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

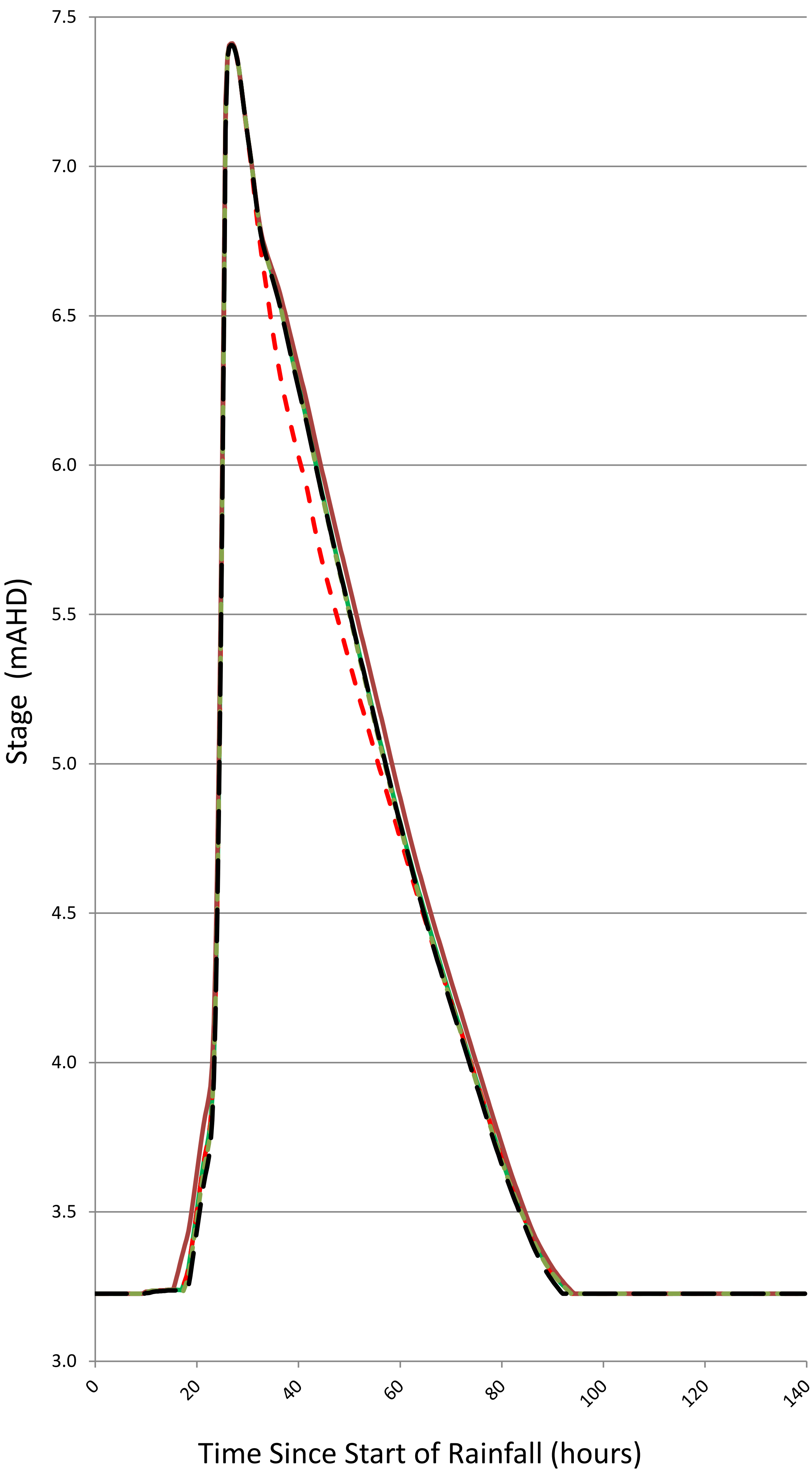
- 1%AEP Existing Stage Hydrograph
- 1%AEP Levee Gates Stage Hydrograph
- 1%AEP Levee Breach Stage Hydrograph
- 1%AEP Pump Failure Stage Hydrograph
- 1%AEP Pump Upgrade Stage Hydrograph
- 1%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K3.3: 1%AEP Stage Hydrograph Comparison on Wollumbin St at Knox Park

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

- 0.2%AEP Existing Stage Hydrograph
- 0.2%AEP Levee Gates Stage Hydrograph
- 0.2%AEP Pump Failure Stage Hydrograph
- 0.2%AEP Pump Upgrade Stage Hydrograph
- 0.2%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K3.4: 0.2%AEP Stage Hydrograph Comparison on Wollumbin St at Knox Park

Prepared By:
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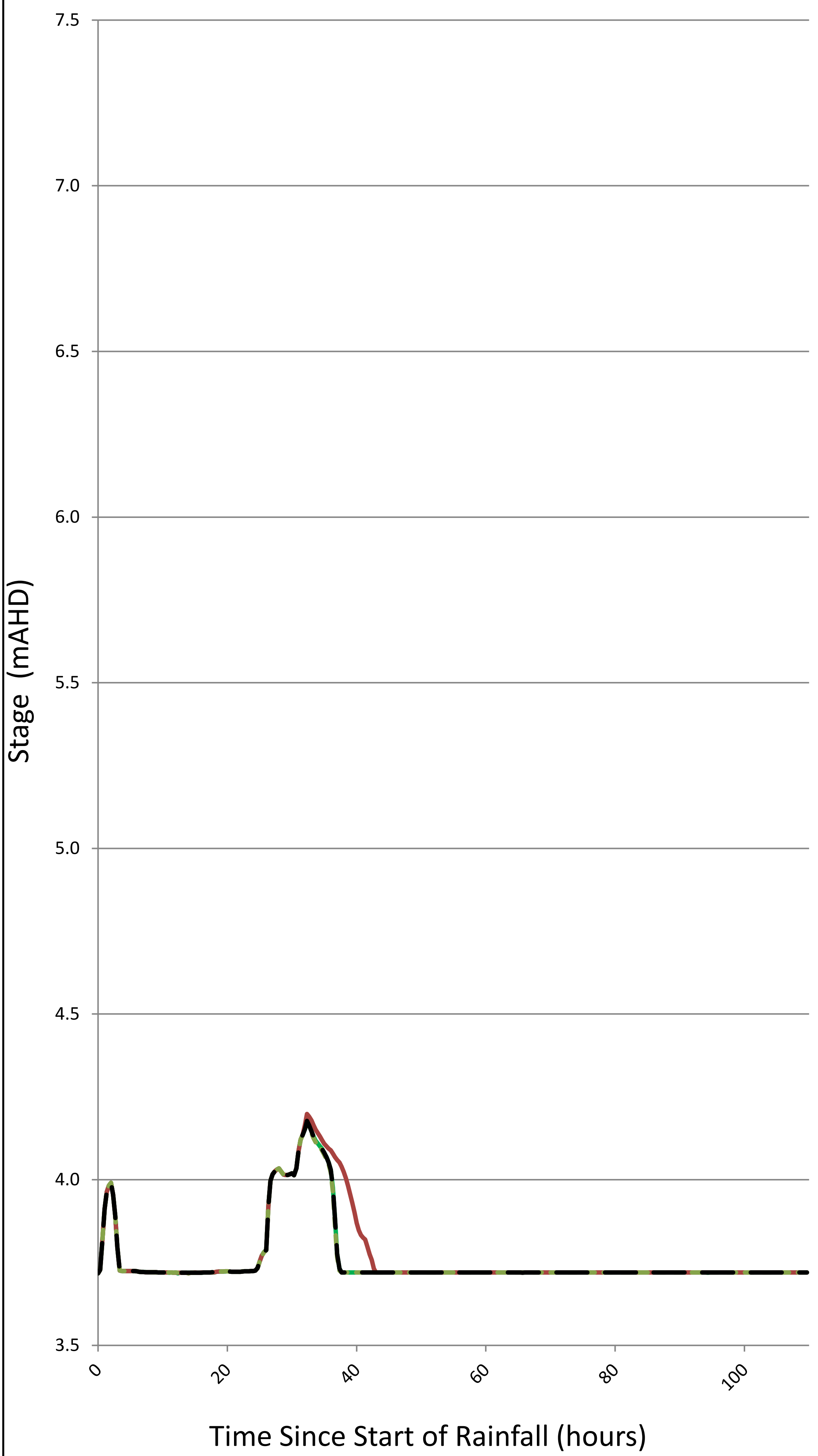
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

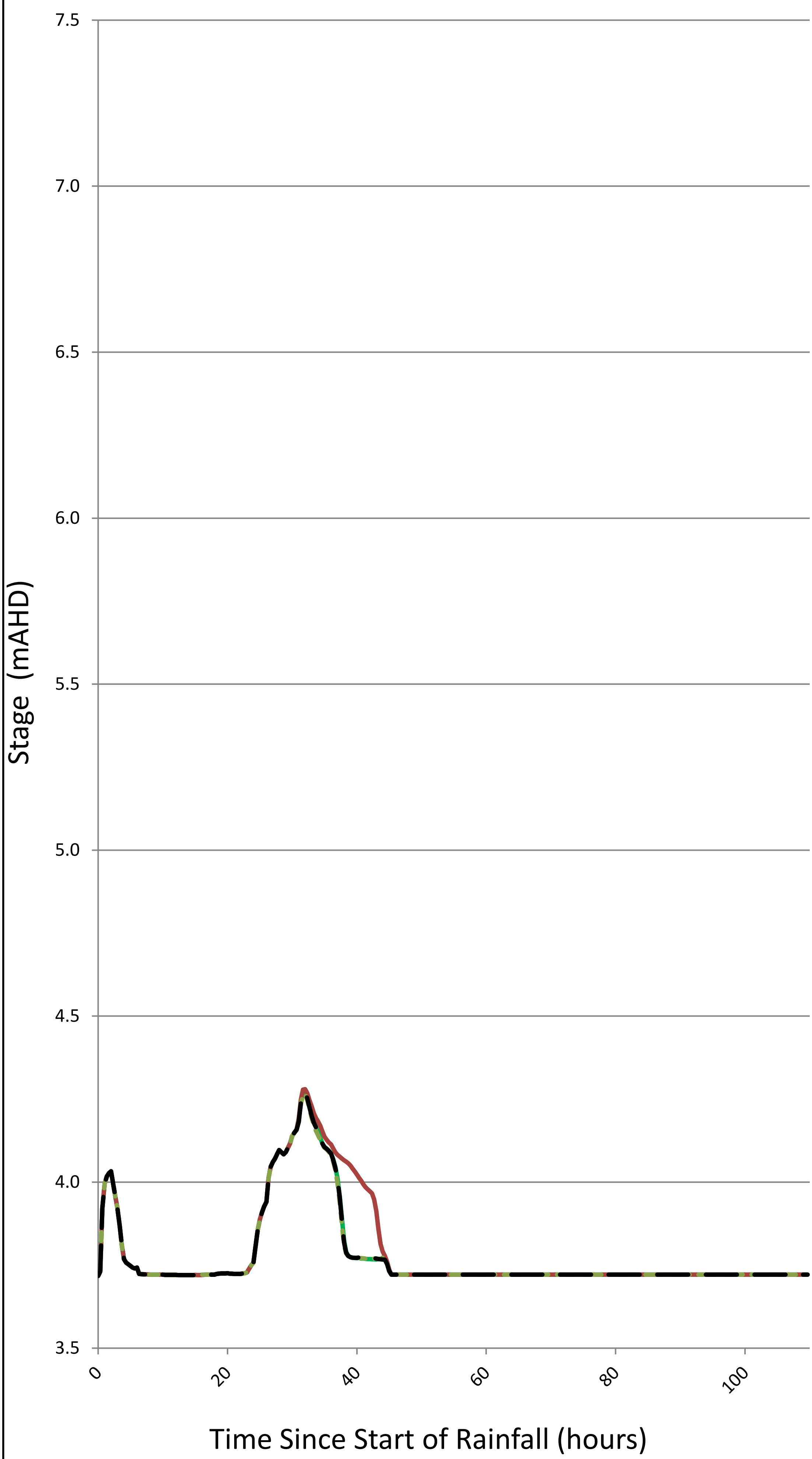
- 20%AEP Existing Stage Hydrograph
- 20%AEP Pump Failure Stage Hydrograph
- 20%AEP Pump Upgrade Stage Hydrograph
- 20%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K4.1: 20%AEP Stage Hydrograph Comparison at Murwillumbah CBD

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



LEGEND:

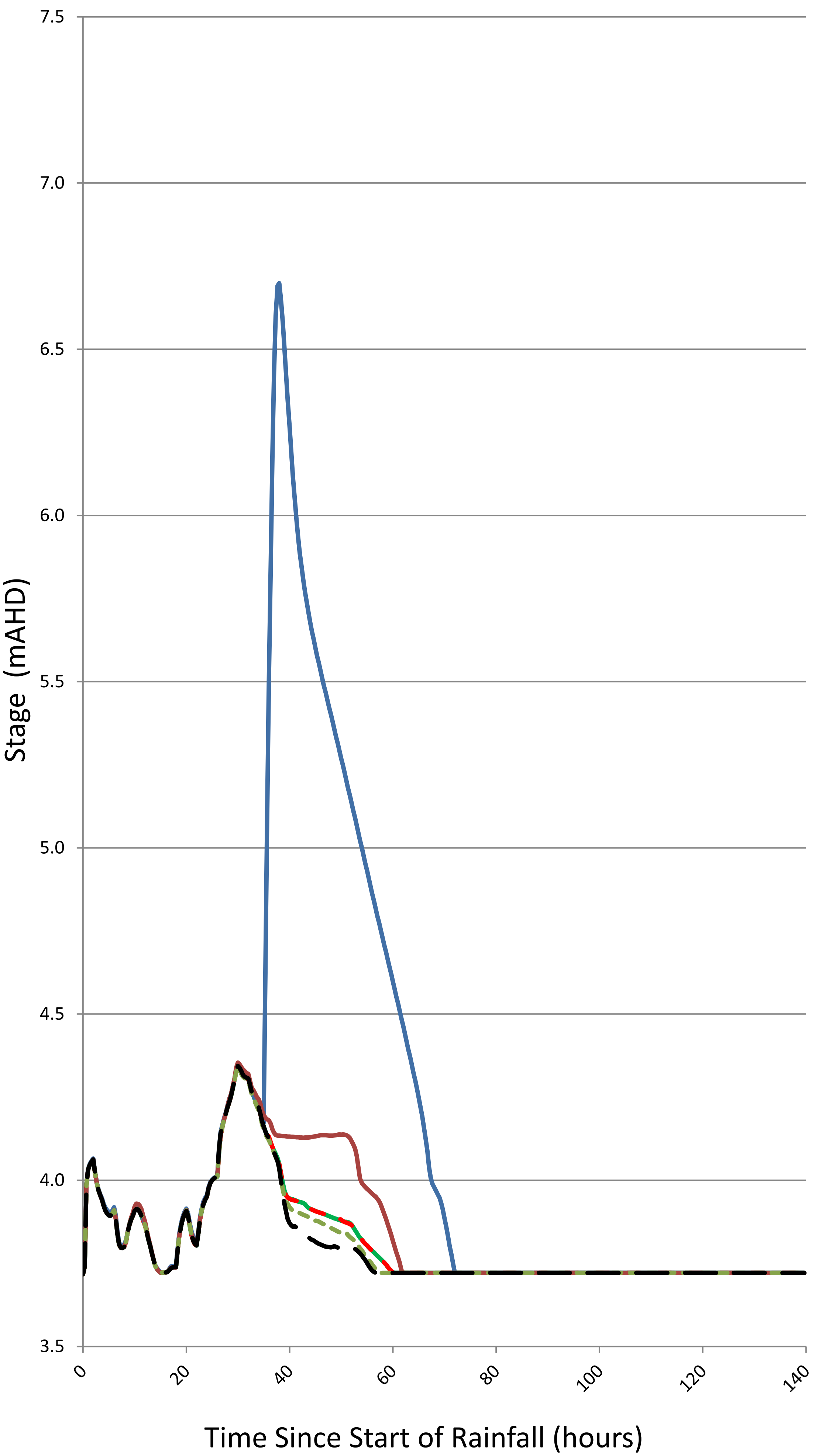
- 5%AEP Existing Stage Hydrograph
- 5%AEP Pump Failure Stage Hydrograph
- 5%AEP Pump Upgrade Stage Hydrograph
- 5%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K4.2: 5%AEP Stage Hydrograph Comparison at Murwillumbah CBD

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

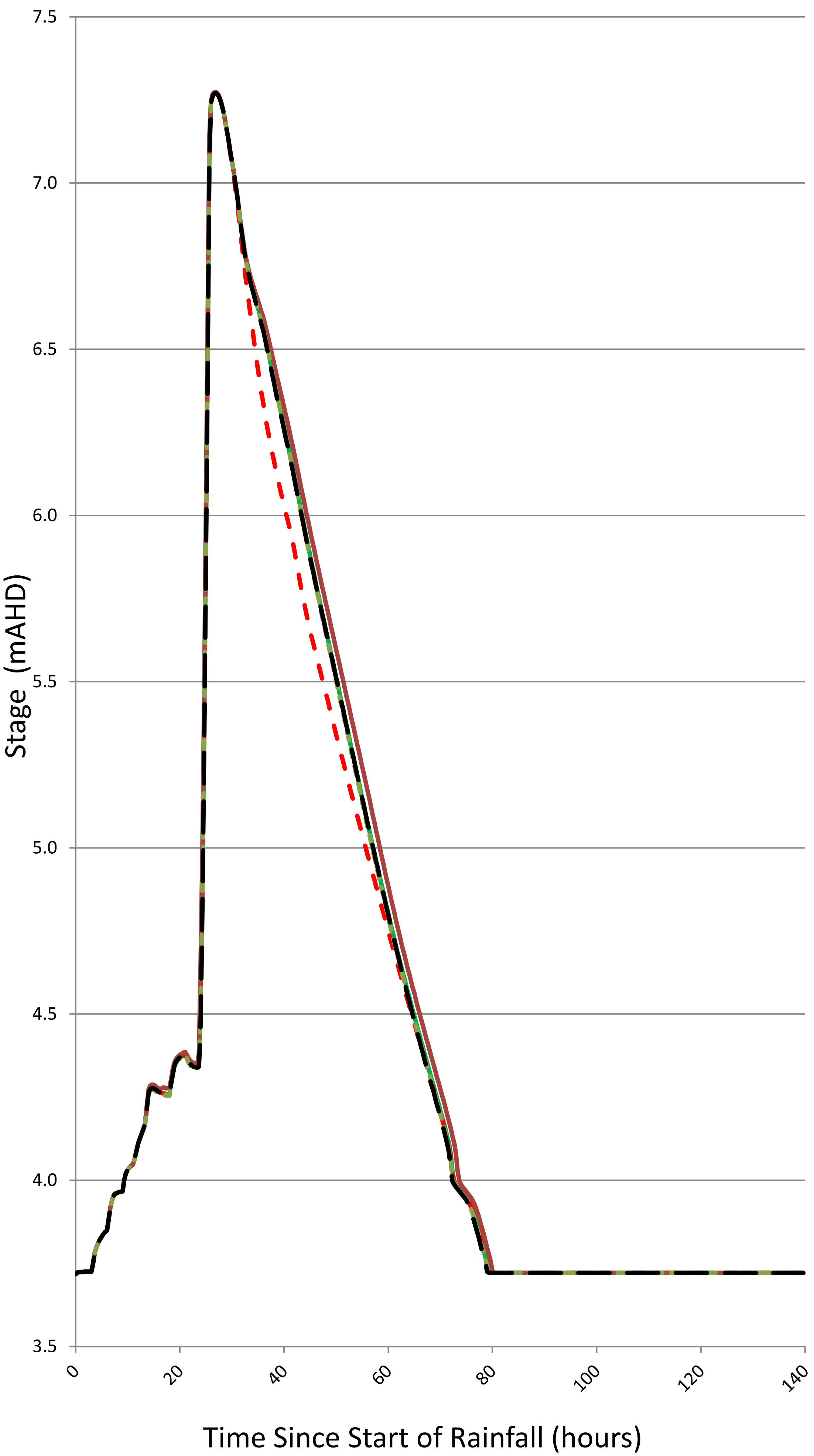
- 1%AEP Existing Stage Hydrograph
- 1%AEP Levee Gates Stage Hydrograph
- 1%AEP Levee Breach Stage Hydrograph
- 1%AEP Pump Failure Stage Hydrograph
- 1%AEP Pump Upgrade Stage Hydrograph
- 1%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K4.3: 1%AEP Stage Hydrograph Comparison at Murwillumbah CBD

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

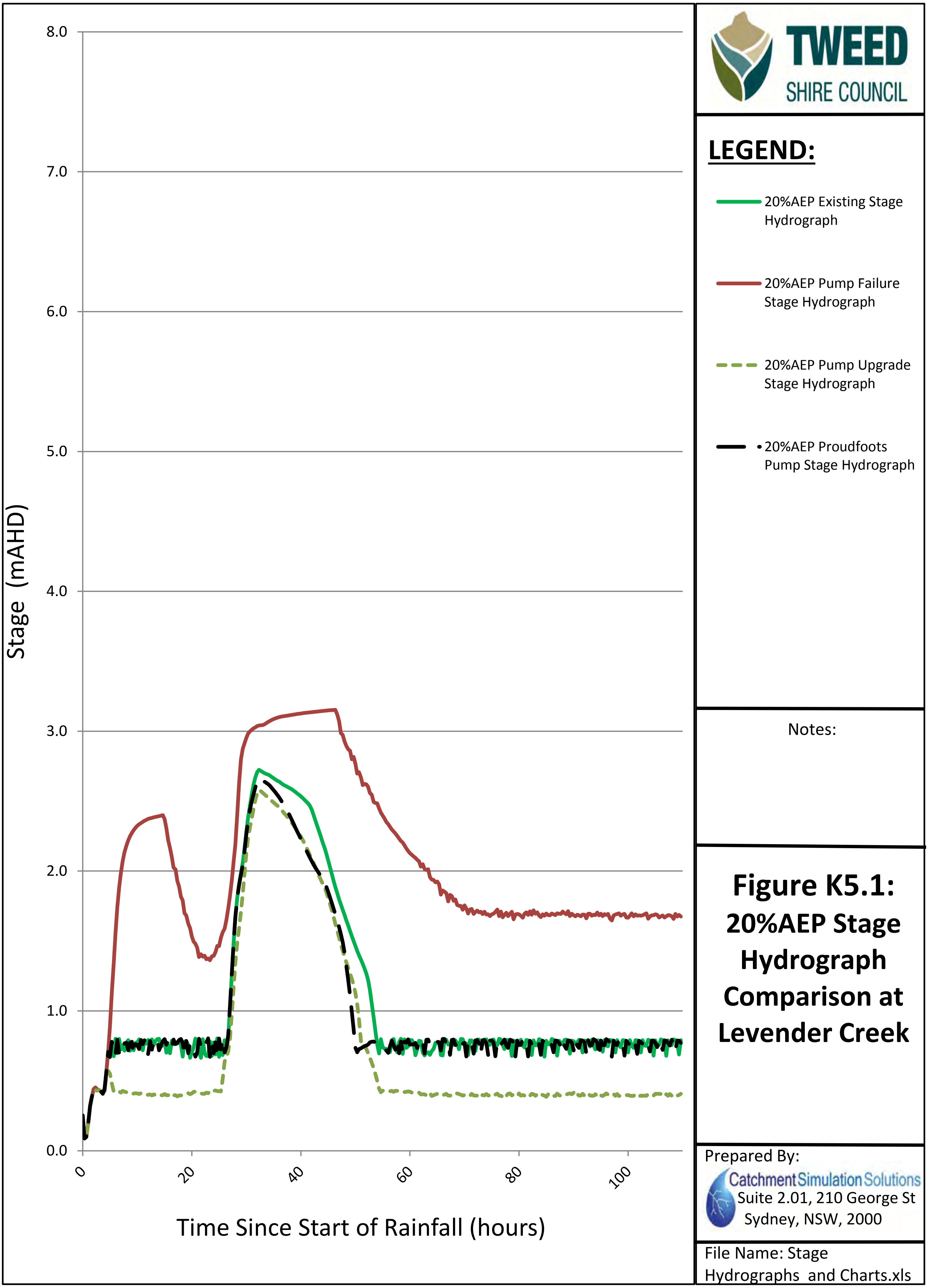
- 0.2%AEP Existing Stage Hydrograph
- 0.2%AEP Levee Gates Stage Hydrograph
- 0.2%AEP Pump Failure Stage Hydrograph
- 0.2%AEP Pump Upgrade Stage Hydrograph
- 0.2%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K4.4: 0.2%AEP Stage Hydrograph Comparison at Levender Creek

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



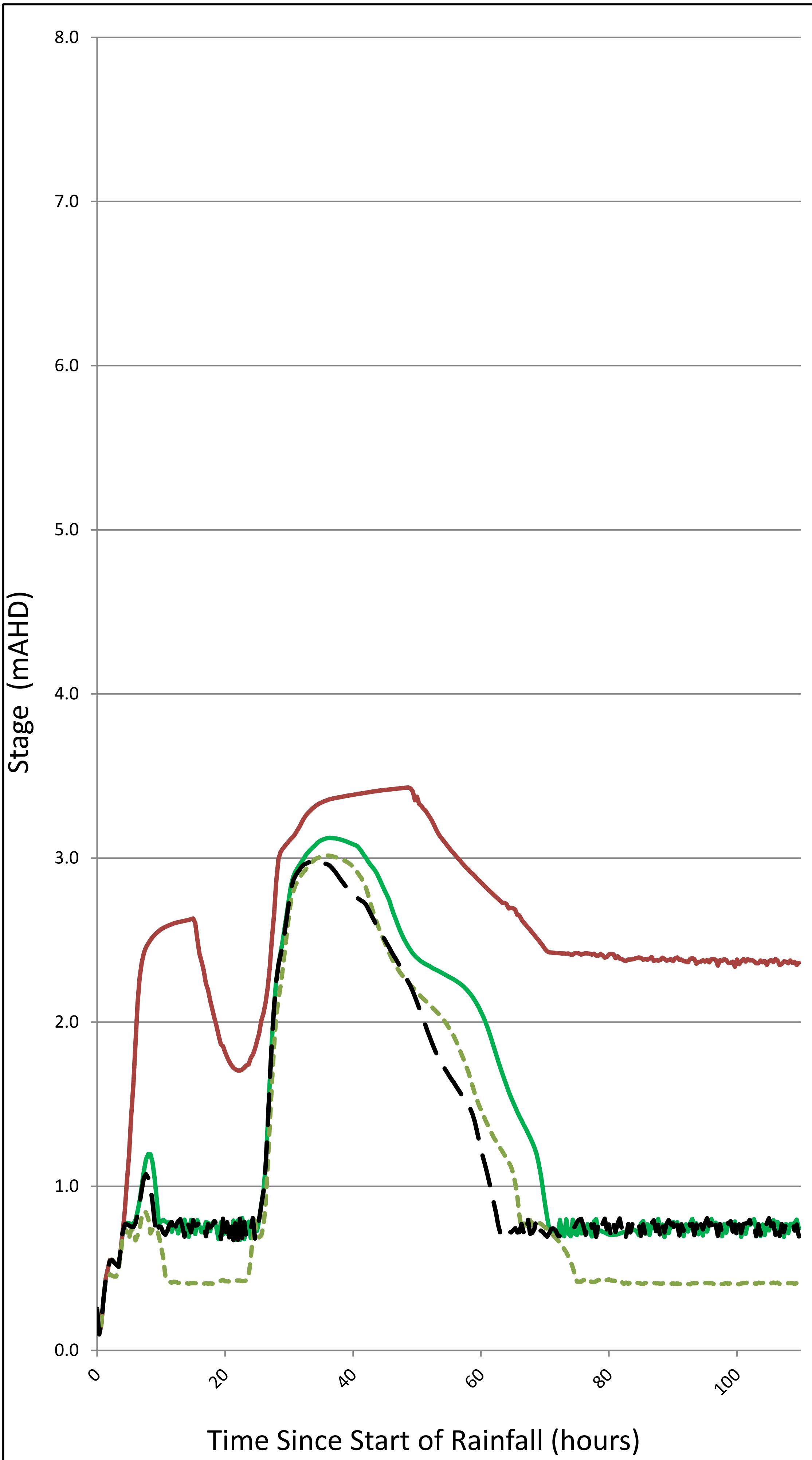
TWEED SHIRE COUNCIL

Notes:

Figure K5.1: 20%AEP Stage Hydrograph Comparison at Levender Creek

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

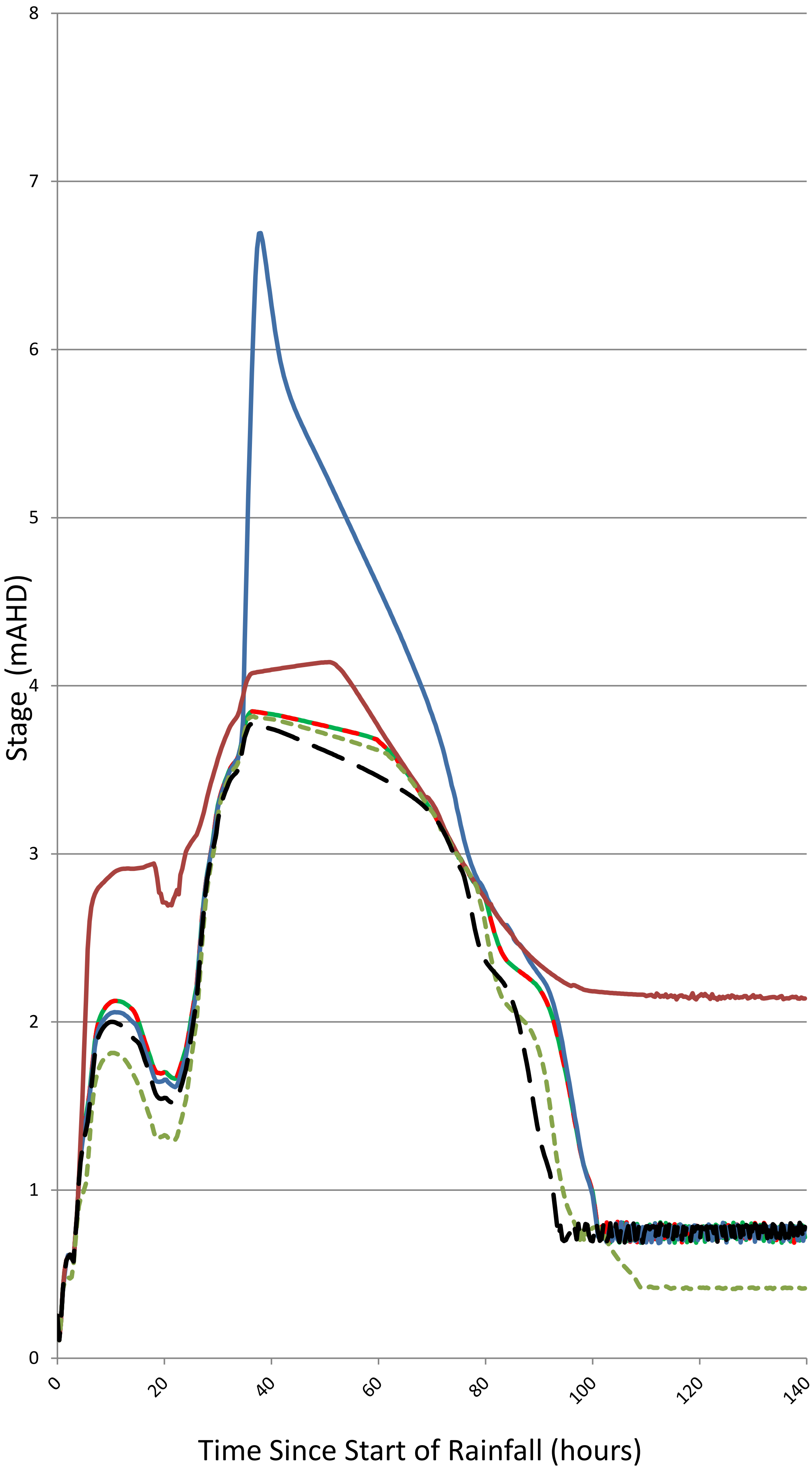
- 5%AEP Existing Stage Hydrograph
- 5%AEP Pump Failure Stage Hydrograph
- 5%AEP Pump Upgrade Stage Hydrograph
- 5%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K5.2: 5%AEP Stage Hydrograph Comparison at Levender Creek

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

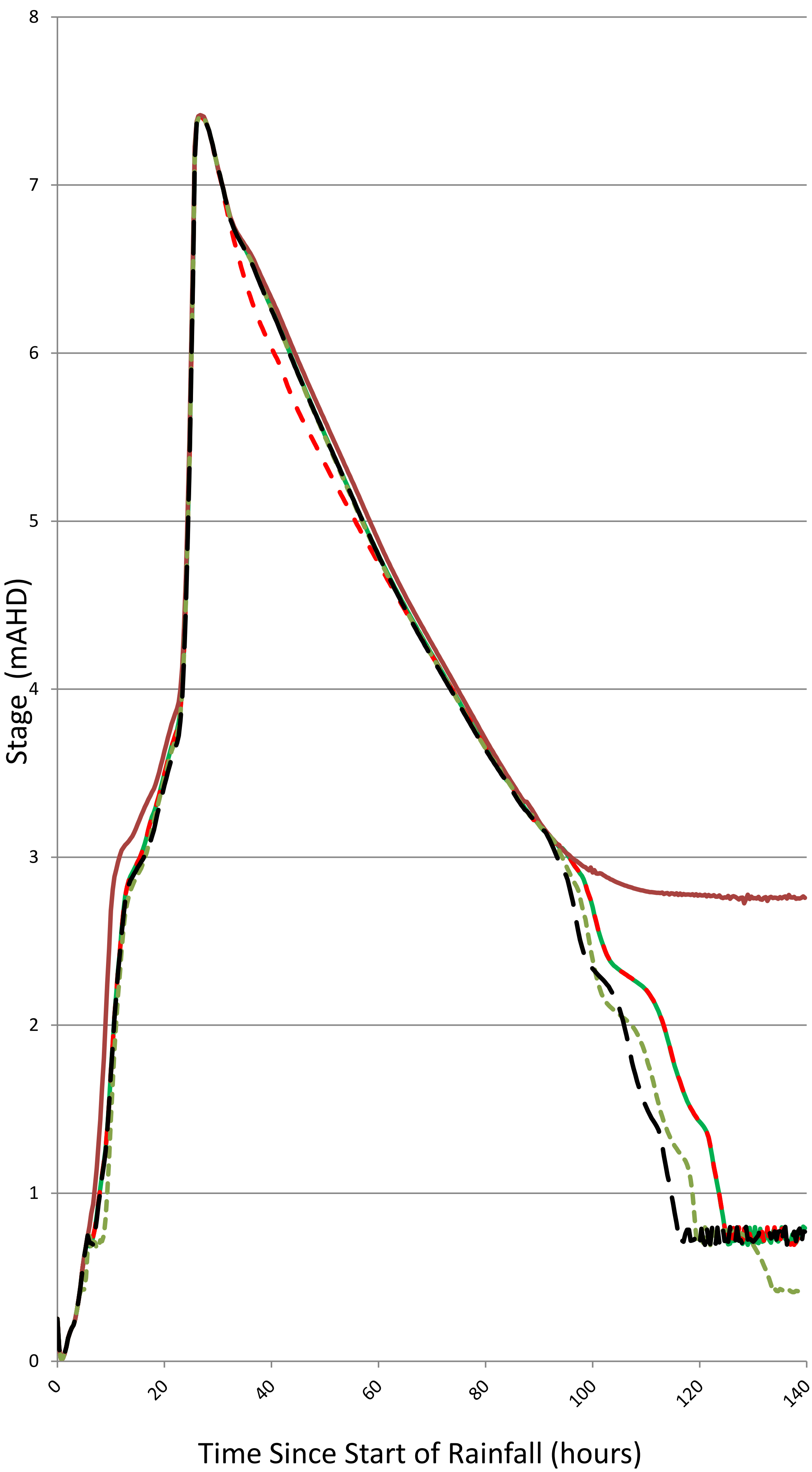
- 1%AEP Existing Stage Hydrograph
- 1%AEP Levee Gates Stage Hydrograph
- 1%AEP Levee Breach Stage Hydrograph
- 1%AEP Pump Failure Stage Hydrograph
- 1%AEP Pump Upgrade Stage Hydrograph
- 1%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K5.3: 1%AEP Stage Hydrograph Comparison at Levender Creek

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls



TWEED SHIRE COUNCIL

LEGEND:

- 0.2%AEP Existing Stage Hydrograph
- 0.2%AEP Levee Gates Stage Hydrograph
- 0.2%AEP Pump Failure Stage Hydrograph
- 0.2%AEP Pump Upgrade Stage Hydrograph
- 0.2%AEP Proudfoots Pump Stage Hydrograph

Notes:

Figure K5.4: 0.2%AEP Stage Hydrograph Comparison at Levender Creek

Prepared By:
Catchment Simulation Solutions
Suite 2.01, 210 George St
Sydney, NSW, 2000

File Name: Stage Hydrographs and Charts.xls