TWEED SHIRE COUNCIL

Addendum to the Murwillumbah CBD Levee & Drainage Study

Final Report

Volume 1 of 2: Report Text & Appendices

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Catchment Simulation Solutions

Addendum to the Murwillumbah CBD Levee & Drainage Study

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EXECUTIVE SUMMARY

Murwillumbah is located in northern New South Wales and is home to over 8,000 people. As shown in **Figure 1**, the township is surrounded by several waterways including:

- Tweed River
- Mayal Creek
- Rous River

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

- Murwillumbah CBD Levee (Commercial Road)
- East Murwillumbah Levee
- Dorothy/William Streets Levee (Brothers)

Although the levees afford protection from river-based flooding, while the river levels are elevated, stormwater is trapped behind the levee and cannot escape under gravity. Therefore, local stormwater flooding can occur for areas behind the levee. This local stormwater flooding is partly managed by pumps; however, the pumps can become overwhelmed during heavy rainfall bursts.

To assist in better managing the flood risk associated with levee overtopping and local catchment runoff behind the levee, Tweed Shire Council commissioned the *'Murwillumbah CBD Levee and Drainage Study'* in 2018. The study evaluated a range of mitigation options that could be potentially implemented to reduce the flood risk for areas of the Murwillumbah CBD located behind the existing levees. This included, amongst other options, pump and stormwater upgrades. At the time the 2018 study was prepared, the pump upgrades were not recommended as they failed to provide a significant reduction in flood levels during large Tweed River floods and other options provided better economic returns on investment in mitigation options.

During the February-March 2022 flood, significant flooding was experienced across the Murwillumbah CBD. This caused damage to residential and commercial properties located behind the levee system. The significant impacts of the 2022 flood across the CBD prompted Council to revisit and expand upon the 2018 study to evaluate additional pump upgrade options.

This included:

- Collection and review of new datasets
- Updates of the hydraulic model to reflect recent stormwater upgrades
- Validation of the hydrologic and hydraulic models to February-March 2022 flood data

- Evaluation of additional pump upgrade scenarios for the Murwillumbah CBD and East Murwillumbah

Computer Model Updates and Validation

Before assessing the additional pump options, the hydraulic computer model used as part of the *'Murwillumbah CBD Levee and Drainage Study'* was updated to take advantage of new datasets that have become available since completion of the 2018 study. This included recent stormwater upgrades across the Murwillumbah CBD.

The updated hydraulic model was then used to simulate the February-March 2022 flood to ensure the model updates were providing reliable descriptions of flood behaviour behind the Murwillumbah CBD and East Murwillumbah levees. This determined that the hydraulic model reproduced surveyed flood marks to within 0.05 metres across the Murwillumbah CBD while the flood marks across East Murwillumbah were reproduced to within 0.1 metres.

The Existing Flooding and Drainage Problem

The hydrologic model used as part of the *'Murwillumbah CBD Levee and Drainage Study'* was also updated to apply hydrologic procedures detailed in Australian Rainfall and Runoff 2019 across the Murwillumbah CBD and East Murwillumbah catchments. This was completed to ensure the addendum followed modern best practice in flood estimation.

The updated models were used to simulate the 20% AEP, 5% AEP and 1% AEP design floods with both elevated river levels as well as lower risk levels. This determined that the performance of the stormwater drainage system behind the levee can be inhibited by elevated water levels, particularly across the lower lying areas bordering Knox park.

A revised flood damage assessment was also completed, and the results of the flood damage assessment were validated against flood damage costs reported by Murwillumbah CBD businesses. This confirmed the calculated flood damages compared well with reported flood damage costs following the 2022 flood. The average annual flood damage cost was determined to be $2.7 million.

Pump Upgrade Options

A total of ten individual pump upgrade options were investigated that focussed on four locations:

- Lavender Creek
- Wharf Street
- King Street
- East Murwillumbah

Each option was evaluated according to:

- how efficient the option was in reducing design flood levels across the CBD and East Murwillumbah
- how it performed from an economic standpoint (i.e., implementation costs versus reductions in flood damage costs)

- how effective each option was at drawing down flood levels (i.e., reducing the total duration of inundation)

Based on the outcomes of the assessment, the following pump upgrade options are considered to provide the best overall performance and are recommended for implementation:

- Lavender Creek: LC2
- Wharf Street: WS4

This would require an investment of more than $6 million over the next 50 years with most of that cost associated with the initial implementation. However, it would provide a reduction in flood damage costs of nearly $5 million.

If full funding for the above options cannot be secured, the following options could be explored as a less capital-intensive pump upgrade option (this combined option would have a life cycle cost of about $3.7 million):

- Lavender Creek: LC1
- Wharf Street: WS2

The following options also afforded notable flood benefits and could be pursued if funding permits:

- King Street: KS1
- East Murwillumbah: EM1

It was also noted that the reliability of any pump system is highly dependent on a reliable power source. Therefore, it is recommended that any new pump system is supplemented with backup generators, where possible, to augment mains power.

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1 INTRODUCTION

1.1 Study Area

Murwillumbah is located within the Tweed Shire Local Government Area (LGA) in northern New South Wales. As shown in **Figure 1**, the township is surrounded by several waterways including:

- Tweed River
- Mayal Creek
- Rous River

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

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

- Murwillumbah CBD Levee (Commercial Road)
- East Murwillumbah Levee
- Dorothy/William Streets Levee (Brothers)

South Murwillumbah, which is located on the eastern floodplain of the Tweed River, is also protected by a lower-level levee.

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 (referred to as "Flood Pumping Station 1") is located near the Lavender Creek crossing of Commercial Road and the second pump (referred to as "Flood Pumping Station 2") is located adjacent to Wharf Park near its intersection with Tumbulgum Road (refer **Figure 1**).

1.2 Purpose of Study

To assist in better managing the flood risk across the Murwillumbah CBD, Tweed Shire Council commissioned the *'Murwillumbah CBD Levee and Drainage Study'* in 2018. The study evaluated a range of mitigation options that could be potentially implemented to reduce the flood risk for areas of the Murwillumbah CBD located behind the existing levees. This included, amongst other options, pump and stormwater upgrades. At the time the 2018 study was prepared, the pump upgrades were not recommended as they failed to provide a significant reduction in flood levels during large Tweed River floods.

During the February-March 2022 flood, significant flooding was experienced across the Murwillumbah CBD. This caused damage to residential and commercial properties located behind the levee system. The significant impacts of the 2022 flood across the CBD prompted Council to revisit and expand upon the 2018 study to evaluate additional pump upgrade options. This included:

- Collection and review of new datasets that have become available since completion of the 2018 study
- Updates of the hydraulic model to reflect recent stormwater upgrades
- Validation of the hydrologic and hydraulic models to February-March 2022 flood data
- Update the Murwillumbah CBD hydrology to reflect revised hydrologic procedures detailed in Australian Rainfall and Runoff 2019
- Evaluation of different pump upgrade scenarios for the CBD and East Murwillumbah

It should be noted that a pump system for the area contained behind the Dorothy/William Streets levee was recommended as part of the *'Murwillumbah CBD Levee and Drainage Study'.* As a result, this area does not form part of this addendum study. That is, the current study focusses on the sections of Murwillumbah contained behind the Murwillumbah CBD and East Murwillumbah levees only.

2 AVAILABLE DATA

2.1 Overview

A range of new and updated datasets have become available since the *'Murwillumbah CBD Levee and Drainage Study'* (Catchment Simulation Solutions, 2018) was completed. A summary of those new datasets is provided below.

A summary of the work completed as part of the 2018 study is also included below to provide context for the current study.

2.2 Murwillumbah CBD Levee and Drainage Study (2018)

The *'Murwillumbah CBD Levee and Drainage Study'* (2018) (herein referred to as the '2018 Study') was prepared by Catchment Simulation Solutions for Tweed Shire Council. The 2018 Study followed on from the *'Tweed Valley Floodplain Risk Management Plan'* (WBM BMT, 2014) which, amongst other recommendations, recommended that a detailed local drainage study be commissioned for Murwillumbah to investigate the flood risk within the township associated with drainage behind the levee as well as levee overtopping.

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 2018 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.
- Average annual flood damages were estimated to be $1.1 million.

A number of options were investigated to assist in reducing and/or better managing the existing flood risk. This included the following pump options:

- Upgrade of the existing Lavender Creek (FPS1) and Wharf Street (FPS2) pumps
- Implementation of a new pump system in Proudfoots Lane

- Implementation of a new pump system behind the East Murwillumbah levee (near George Street)
- Implementation of a new pump system behind the Dorothy Street levee

The outcomes of the 2018 study determined that each pump option would assist in reducing existing flood levels behind each levee. However, the capacity of the pumps were overwhelmed during larger floods. As a result, the reduction in flood damage costs afforded by the pumps was low relative to the implementation costs yielding a poor economic outcome. As a result, only the Dorothy Street pump system was ultimately recommended.

Notwithstanding, the results of the pump assessment did provide insights into how the performance of the options could be potentially improved. This included:

- Providing higher capacity pumps
- Upgrading the local stormwater system that distributes runoff to the Wharf Street pump (i.e., the capacity of the stormwater system appears to be the limiting factor rather than the pump capacity)
- Developing alternate trigger levels for the East Murwillumbah pump

Overall, the 2018 Study provides a lot of valuable information to assist with the current addendum study. This includes a 'base' flood model for assessing hydraulic impacts as well as a starting point for developing more efficient pump upgrade options.

However, as the 2018 study was completed prior to the release of 'Australian Rainfall and Runoff – A Guide to Flood Estimation' (Ball et al, 2019) it does not take advantage of the most recent guidance for flood estimation. In addition, some upgrades of the local stormwater system have been completed. Therefore, there is a need to update the hydrology and hydraulic model to ensure the current addendum study reflects contemporary conditions across Murwillumbah and follows modern best practice in defining hydrology.

2.3 Topographic Information

2.3.1 LiDAR

Topography across the Murwillumbah CBD was largely defined in the 2018 study based upon LiDAR that was collected in 2014. More recent LiDAR was collected in 2020 and this information was made available for use as part of the study. However, before it was applied as part of the study, it was reviewed to ensure it was fit-for purpose and would provide a reliable representation of the ground surface elevations across the CBD.

A terrain difference map was prepared by subtracting the 2014 LiDAR elevations from the 2020 LiDAR elevations. The resulting difference map is provided in **Plate 1** and shows the magnitude and locations of differences in ground elevations between the two LiDAR datasets (only elevation difference of more than 0.1 metres are shown).

Plate 1 shows that in areas with minimal tall vegetation (e.g., sporting fields), the two LiDAR datasets commonly agree to within ±0.1 metres. However, in areas of taller vegetation (e.g., trees, crops, sugar cane), the 2020 LiDAR is most commonly higher than the 2014 LiDAR. A more detailed review of the 2020 LiDAR in these areas indicated that there were topographic high points that appeared to be inconsistent with adjoining ground elevation as well as field observations. Therefore, there were concerns that the 2020 LiDAR did not correctly identify and remove all non-ground elevation points.

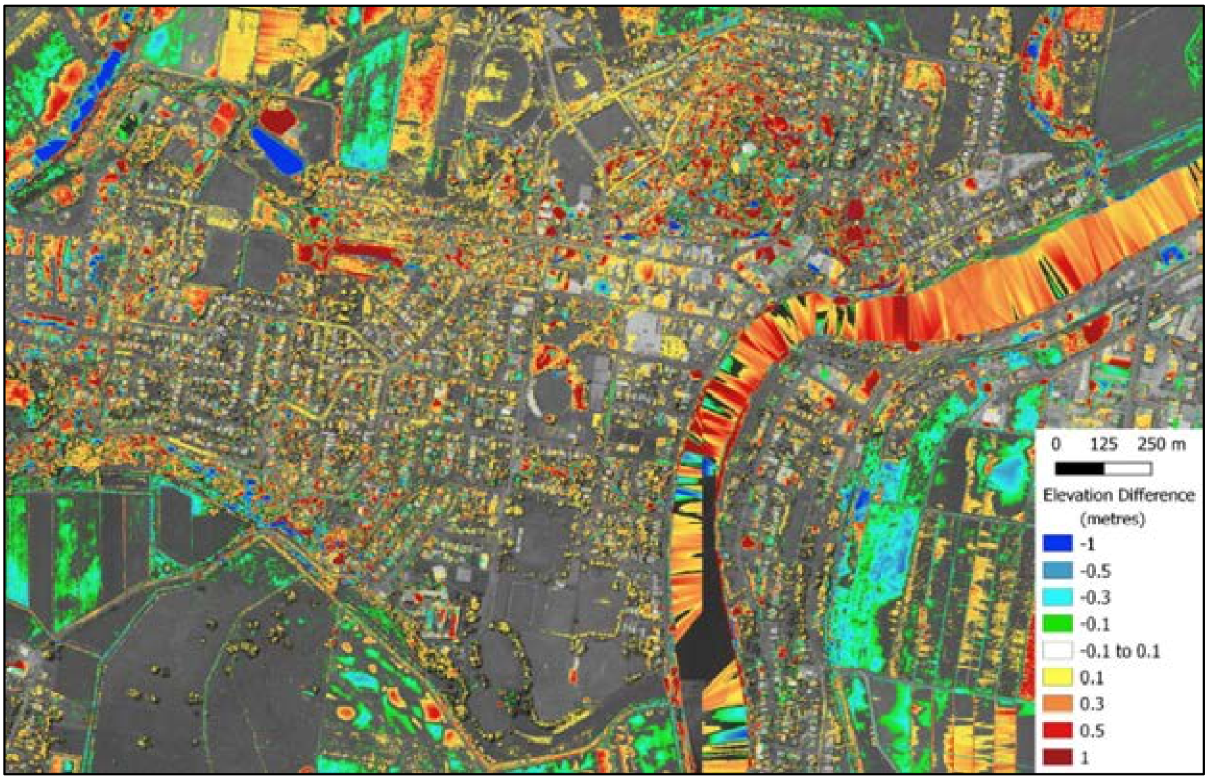


Plate 1 LiDAR difference map (2020 LiDAR – 2014 LiDAR)

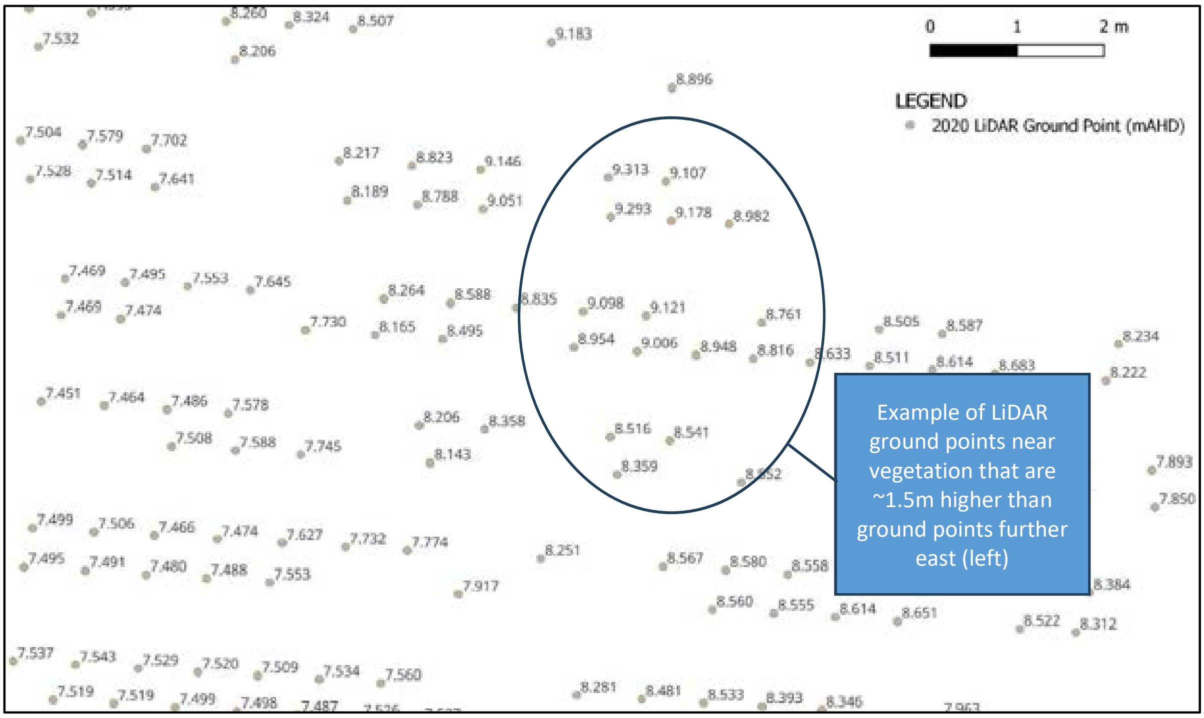


Plate 2 Example of 2020 LiDAR ground point elevations

A detailed review of the 2020 LiDAR ground points was subsequently completed in areas where more significant terrain differences were apparent. An example of one such area (located near the earthen embankment portion of the Commercial Road levee) is provided in **Plate 2**. It shows ground elevation points that vary by more 1.5 metres over a 5-metre horizontal distance across an area where such topographic differences are not apparent in reality.

As a result of this review, the 2020 LiDAR was considered to provide a poorer representation of ground surface elevations relative to the 2014 LiDAR. Therefore, the 2014 LiDAR was retained as part of the current assessment.

2.4 Plans

2.4.1 Stormwater

Several work-as-executed plans of recent stormwater and drainage upgrade works were provided by Council. This includes details on pipe sizes, pipe alignments, pit locations and pit inverts. The plans included:

- Main Street & Proudfoots Lane drainage reconstruction
- Murwillumbah Street drainage upgrade
- Nullum Street drainage upgrade
- Condong Street drainage upgrade
- Brisbane Street drainage upgrade

2.4.2 Pumps

Plans of the two CBD flood pumping stations along with pump curves were also provided by Council. This includes details on inverts of pipes and the Lavender Creek channel, elevations at which the pumps are activated and details of drainage infrastructure between the pumps and the river.

2.5 2022 Flood Data

2.5.1 Rainfall Gauges

Many gauges collected rainfall information across the Tweed River catchment February-March 2022 flood. A summary of the gauges contained within the catchment that were active during the flood is provided in **Table 1**. The recorded daily rainfall totals for the period between 24 February and 2 March is also included along with the total rainfall recorded over the full event. The gauge list is arranged from closest to the Murwillumbah CBD to furthest away.

The daily rainfall totals in **Table 1** show that most of the rain fell between the 26 and 28 February. However, significant rainfall also occurred on the 23 and 24 February meaning the catchment would have been saturated prior to the main rainfall burst.

Table 1 Active rainfall gauges during the 2022 flood

Number	Name	Rainfall* (mm)									
		23 Feb	24 Feb	25 Feb	26 Feb	27 Feb	28 Feb	1 Mar	2 Mar	3 Mar	TOTAL
58186	Murwillumbah	24	121	24	6	161	412	0	10	7	758
58005	Bray Park	28	117	65	22	125	285	70	0	10	712
558082	Clothiers Creek	22	77	18	3	154	423	0	2	4	699
58193	Eungella	35	157	56	11	148	376	0	5	13	788
558014	Tumbulgum	26	97	10	2	148	347	0	5	5	635
58011	Chillingham Bridge	57	107	90	16	165	408	0	6	5	849
558011	Duranbah Repeater	18	70	4	2	167	363	0	2	4	626
540354	Tomewin	65	74	62	17	147	458	0	6	4	829
558081	Numinbah Repeater	75	64	181	63	205	384	0	2	7	974
58167	Uki	37	161	57	25	136	384	0	8	9	808
558032	Bald Mountain	77	94	95	26	173	373	0	1	7	839
558090	Kingscliff WWTP	18	66	3	7	143	236	0	1	3	474
558085	Bilambil	44	72	26	7	137	319	0	1	6	606
558010	Barneys Point	13	60	2	3	123	182	0	2	2	385
558088	Tyalgum Bridge	44	98	72	12	125	344	0	0	8	695
558028	Clarrie Hall Dam	32	136	75	12	93	416	0	4	11	768
58129	Kunghur	180	70	16	127	522	260	1	15	2	1191
558034	Upper Main Arm	25	183	60	33	156	353	0	5	17	815
58019	Doon Doon	144	90	55	130	758	397	3	24	2	1601

NOTE: * Rainfall totals reflect cumulative 24 hour depths up to 9am.

In some sections of the upper Tweed River catchment, rainfall totals of around 1500mm were experienced. While around Murwillumbah, nearly 1000mm of rainfall was recorded. Therefore, some sections of the catchment experienced their average annual rainfall depth in less than 2 weeks.

2.5.2 Water Level Gauges

Several gauges also collected stream water levels throughout the February-March 2022 flood. This included the Murwillumbah and Murwillumbah Bridge gauges. The peak recorded water levels at both gauges are provided in **Table 2**. Also included in **Table 2** are the peak water levels for other recent floods to help understand the relative magnitude of the 2022 flood. This confirms that the 2022 flood was the largest flood over the past decade.

Table 2 Active water level gauges during the 2022 flood

Number	Name	Peak Water Level (mAHD)			
		2022	2017	2016	2012
58186	Murwillumbah	6.51	6.35	-	4.88
558067	Murwillumbah Bridge	6.25	5.90	3.39	4.66

2.5.3 Photographs and Videos

A number of photograph and videos of the 2022 flood were provided by Council. This included photos and videos captured by Council staff, media as well as residents and business owners within the CBD. A selection of photos that were captured during the event are included in **Appendix A**.

2.5.4 Flood Marks

A survey of flood marks was completed by Council once floodwaters had receded. This was largely informed by debris marks which would typically reflect water levels at the peak of the flood. A total of 337 flood marks were surveyed across the LGA. This included 33 flood marks across the Murwillumbah CBD and 27 flood marks across East Murwillumbah.

The flood marks showed that the peak water level across much of the Murwillumbah CBD was around 4.54mAHD. This reflects a water level that is more than 1 metre above the natural ground levels in some sections of the CBD and helps to demonstrate the notable depths of inundation that were experienced.

The surveyed flood marks across East Murwillumbah show more variability but are most commonly between 5.1 and 5.3 mAHD. This is again, more than 1 metre higher than some areas of East Murwillumbah.

Flood marks were also collected around the town levees. In conjunction with the photos and videos that were collected, it showed that the Commercial Road levee overtopped south of Les Cave Field as well as across the Murwillumbah High School sports field (refer **Plate 3**) and the East Murwillumbah levee was overtopped east of Charles Street.

Plate 3 Overtopping of the Commercial Road Levee in 2022 Flood (image provided via YouTube by *Offtopic*: https://www.youtube.com/watch?v=UsPF5DTl44U)

2.5.5 Flood Damages

A Business Flood Impact assessment was compiled by Tweed Shire Council following the 2022 flood. This involved distribution of a survey to understand the financial impacts to impacted business owners. Although the survey was distributed to all businesses within the Tweed LGA, information on impacts to the Murwillumbah CBD could be extracted.

The questionnaire responses from the Murwillumbah CBD businesses showed the following cumulative losses (note that all monetary values are estimates):

- Building repairs: $1.48 million
- Equipment replacement: $2.21 million
- Loss of revenue: $1.62 million
- Total financial impact: $5.3 million

The questionnaire responses showed that around 30% of businesses took 2-3 months to reopen while 9% took more than 3 months to re-open.

3 EXISTING FLOOD ASSESSMENT

3.1 General

The *'Murwillumbah CBD Levee and Drainage Study'* (Catchment Simulation Solutions, 2018) used a WBNM hydrologic model and a TUFLOW hydraulic model to provide an understanding of the nature and extent of the flood risk. These models were considered appropriate for application as part of the current study.

However, as discussed in Section 2.5, a significant amount of data was collected during and after the February/March 2022 flood. This provides an excellent opportunity to further validate the performance of the models. The outcomes of the additional model validation are provided in Section 3.2.

As noted in Section 2.2, the 2018 Study did not take advantage of 'Australian Rainfall and Runoff – A Guide to Flood Estimation' (Ball et al, 2019). Therefore, the design flood hydrology for the areas located behind the levee were updated to take advantage of this updated guidance. The outcomes of the updated design flood simulations are provided in Section 3.3.

3.2 Model Validation

3.2.1 Hydrology

As discussed in Section 2.5.1, the February-March 2022 flood was produced by heavy rainfall over approximately 7 days. Most of the rain fell within the broader catchment between the 26 and 28 February. However, significant rainfall also occurred on the 23 and 24 February meaning the catchment would have been saturated prior to the main rainfall burst.

The recorded rainfall information that was summarised in **Table 1** was used as the basis for developing a rainfall isohyet map, which is presented in **Figure 2**. It shows that in some sections of the upper Tweed River catchment, rainfall totals or around 1500mm were experienced. Around Murwillumbah, around 1000mm of rainfall was recorded.

The recorded rainfall was also applied to the WBNM model and the WBNM model was used to simulate rainfall-runoff process for the 2022 event.

3.2.2 Hydraulics

The simulated flow hydrographs generated by the WBNM model were then applied to the TUFLOW hydraulic model. The TUFLOW model was used to simulate flood hydraulics for the 2022 flood and generated key flooding characteristics such as water depths and water levels. This permitted the simulated water levels to be compared to recorded gauge levels as well as the flood mark levels (refer Section 2.5.4).

The simulated water depths for the Murwillumbah CBD and East Murwillumbah are provided on **Figures 3.1** and **3.2** respectively. Also included on **Figures 3.1** and **3.2** are the surveyed flood mark elevations and the simulated peak flood level at each flood mark location.

Flood levels at the Murwillumbah Bridge stream gauge are provided in **Appendix C** as **Figure C1**. The simulated water levels produced by the TUFLOW model are also superimposed. Similarly, a comparison between recorded water levels at the Lavender Creek pumping station and simulated water levels is provided in **Figure C2**.

The simulated peak flood levels in **Figures 3.1** and **3.2** generally show a good reproduction of the surveyed flood marks. The surveyed flood marks across the CBD are generally reproduced to within 0.05 metres while the flood marks across East Murwillumbah are reproduced to within 0.1 metres (although, as noted in Section 2.5.4, there are some notable variations in surveyed flood mark elevations in this area).

Figure C1 in **Appendix C** also shows that the TUFLOW model provides a reasonable reproduction of the recorded time variation in water levels within the Tweed River.

Figure C2 in **Appendix C** also indicates that the TUFLOW model is providing a reasonable reproduction of the time variation in water levels behind the CBD levee. It is acknowledged that the simulated peak water level is lower than the recorded water level, however, the recorded peak water level is well above the flood mark elevations for the CBD indicating the recorded peak level may be over-stated.

Council also noted that during the 2022 flood, water was observed travelling from the Wharf Street pump catchment in a southerly direction towards Knox Park and then later, water was observed travelling north from the Knox Park area towards Wharf Street. As shown by the velocity vectors in **Plate 4** and **Plate 5**, the simulated directions of water movement at different stages of the 2022 flood appear to replicate these observations (although it appears that the movement of water towards Wharf Street was much slower than the movement of water towards Knox Park as indicated by the smaller vectors).

Therefore, it appears the flood models are providing a reasonable reproduction of the 2022 flood and are suitable for defining design flood behaviour and the hydraulic performance of various pump upgrade options.

Flood Damages

Flood damage estimates were calculated as part of the project to understand the economic impacts of flooding on the Murwillumbah CBD and East Murwillumbah communities. The damage estimates employed the same flood damage curves that were used as part of the 'South Murwillumbah Floodplain Risk Management Study' (Catchment Simulation Solutions, 2019). These damage curves were refined based on damage estimates across South Murwillumbah that were collated following the 2017 flood.

As outlined in Section 2.5.5, an estimate of the financial impact of the 2022 flood on commercial properties within the Murwillumbah CBD was completed. This determined that the combined economic impact to the 42 commercial properties that responded to the

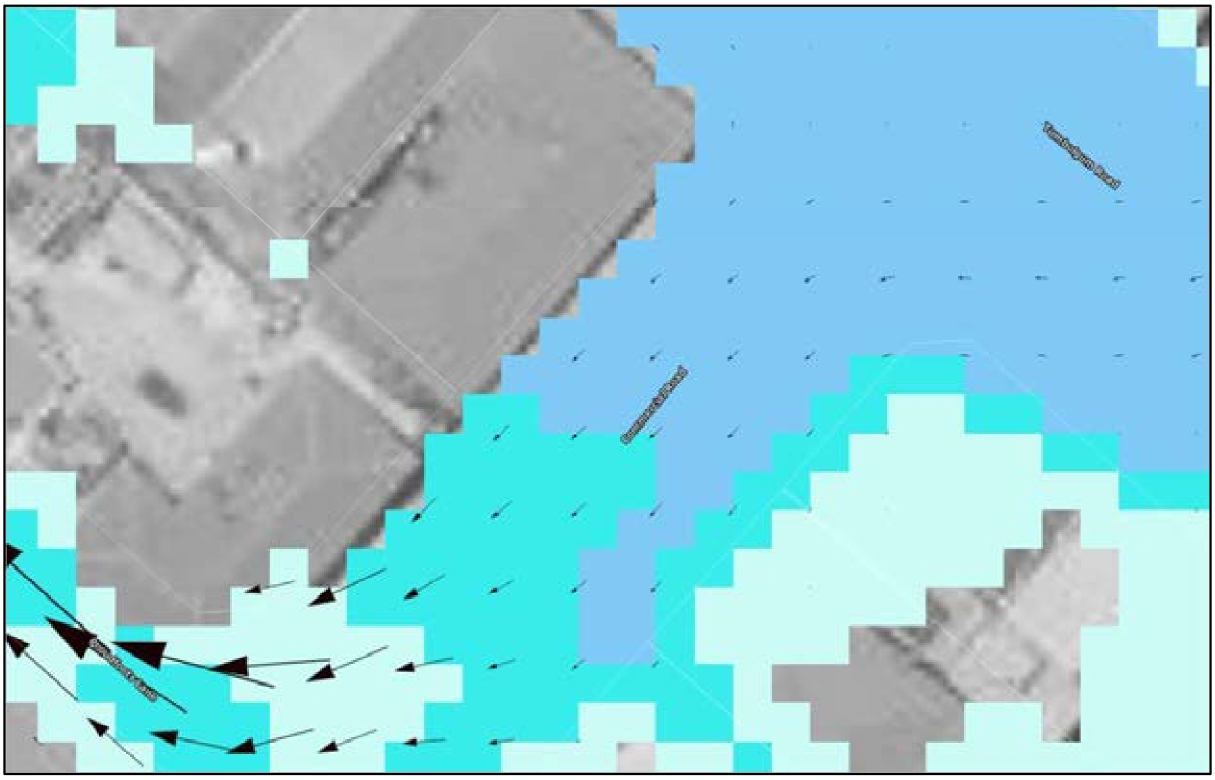


Plate 4 Simulated velocity vectors showing water moving south along Commercial Road at 7am on 28 February

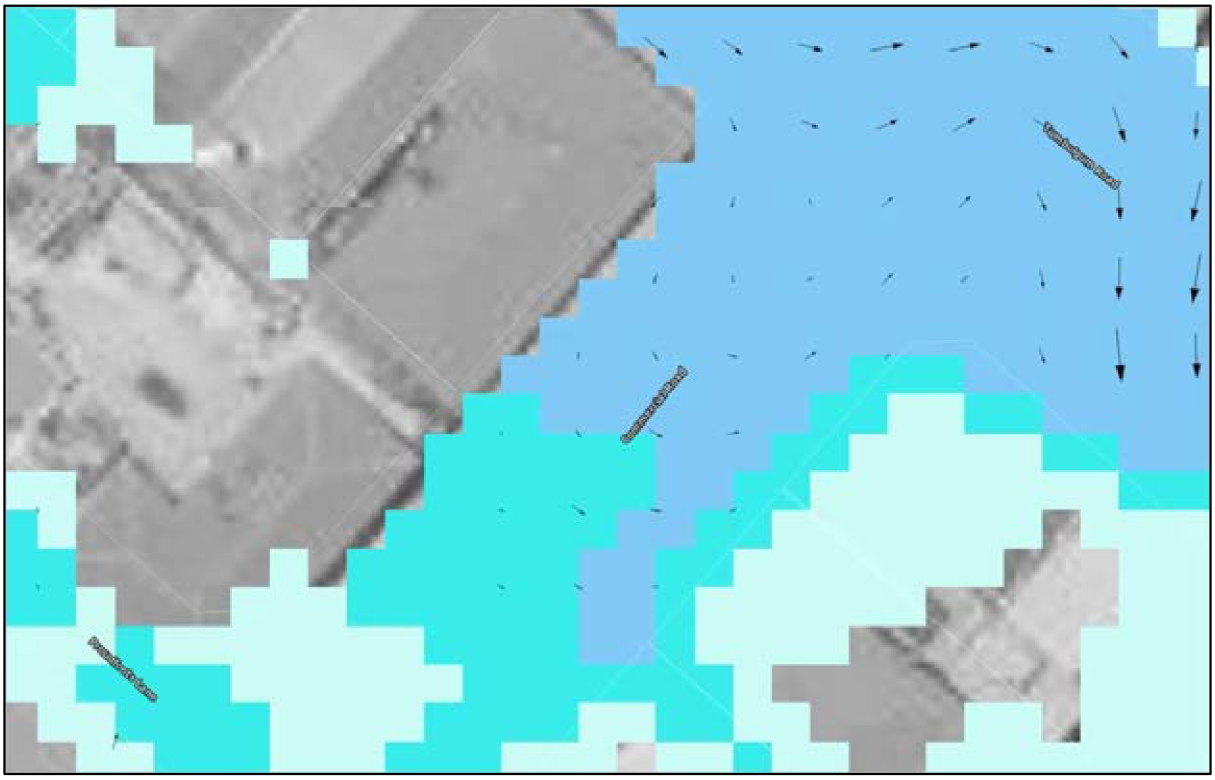


Plate 5 Simulated velocity vectors showing water moving north along Commercial Road at 4pm on 28 February

Business Flood Impact assessment amounted to about $5.3 million (i.e., average flood damage cost = ~$126,000 per property). This information was used to validate the flood damage calculations prepared as part of the current study by comparing the flood damages estimates with the reported flood damage costs at a selection of the property locations. This yielded an average flood damage estimate of ~$112,000 per property, which is sufficiently close to the reported damage cost of to indicate the flood damage estimates are reasonable.

3.3 Existing Design Flood Behaviour

3.3.1 'Base' Design Flood Behaviour

Hydrology

The validated WBNM model was used to simulate rainfall-runoff behaviour for the local Murwillumbah subcatchments for the design 20% AEP, 5% AEP and 1% AEP based on procedures set out in of 'Australian Rainfall & Runoff' (Ball et al, 2019). This included the following steps/inputs:

- Point design rainfall depths for Murwillumbah were downloaded from the Bureau of Meteorology's IFD webpage. As the local catchments draining through the CBD and East Murwillumbah comprise less than 1 km^2, no areal reduction factors were applied to the point rainfall depths before application to the WBNM model.
- Probability neutral "burst" losses were downloaded from the ARR2019 data hub. This resulted in initial rainfall losses of between 3.8 mm and 32.4 mm being applied to the WBNM model.
- The ARR2019 jurisdictional advice for NSW recommends that the continuing loss rate documented on the Data Hub be reduced by 60% before application to pervious surfaces. The "raw" loss rate documented on the data hub is 3.4 mm/hr. Therefore, the adjusted loss rate is 1.36 mm/hr and was adopted for application to pervious surfaces. A continuing loss rate of 0 mm/hr was adopted for impervious areas.
- ARR2019 employs 10 different temporal patterns for each AEP/storm duration to define the time variation in rainfall during each storm. The temporal patterns were downloaded from the ARR data hub and were used to simulate the temporal distribution of rainfall for each design storm. In accordance with ARR2019 for catchments with an area less than 75 km^2, the "point" temporal patterns rather than "areal" temporal patterns were selected to describe the temporal variation in rainfall.

The WBNM model was used to simulate the full suite of 20% AEP, 5% AEP and 1% AEP storms based on the inputs listed above. The Storm Injector software was used to automate the simulation of the more than 700 design storms. The Storm Injector software was also used to help identify the critical storm durations and representative temporal pattern for each design storm and critical duration.

The critical duration is most commonly selected as the duration that produces the highest average peak discharge (based on consideration of all 10 temporal patterns for each duration). However, it was noted that the water levels for the areas contained behind each levee (i.e., the focus of the current study) are more dependent on the volume of rain that falls rather than the peak discharge. Therefore, an alternate metric was used to identify the critical duration. This was based on the duration that produces the highest total volume of runoff once the peak discharge exceeds 1.4 m^3/s. This flow rate was adopted as it corresponds to the approximate combined peak capacity of the existing pump system for the Murwillumbah CBD (therefore, any volume above this discharge will be 'left behind' and result in a build-up of water behind the levee). This resulted in the following critical durations being defined:

- 20% AEP: 36 hours
- 5% AEP: 36 hours
- 1% AEP: 48 hours

All 10 temporal patterns for the critical duration listed above were then simulated using the TUFLOW model to determine the average design flood level behind the levees for each flood frequency. The temporal pattern that generated a peak flood level slightly above the average flood level was subsequently adopted as the most representative temporal pattern for the storm frequency and duration. This resulted in the following temporal patterns (TP) being adopted:

- 20% AEP: TP 4936
- 5% AEP: TP 4920
- 1% AEP: TP 2739

It should be noted that the hydrology for riverine flooding was not modified (as it is not the focus of the current study). That is, inflows for the Tweed and Rous Rivers remained unchanged from the *'Murwillumbah CBD Levee and Drainage Study'* (2018).

Hydraulics

The revised critical 20% AEP, 5% AEP and 1% AEP flow hydrographs were subsequently applied to the TUFLOW model and the TUFLOW model was used to route the flow hydrographs across the model area.

Peak water depths were extracted from the results of the modelling and are provided in **Figures 4**, **5** and **6**.

Figures 4 and **5** show broadly similar inundation depths and extents across the Murwillumbah CBD and East Murwillumbah during the 20% AEP and 5% AEP floods. However, peak water levels and depths during the 5% AEP flood are generally 0.2 to 0.3 metres higher than the 20% AEP flood.

Figure 6 shows that water depths are predicted to increase significantly during the 1% AEP flood. This is associated with the southern section of the Murwillumbah CBD levee as well as the Murwillumbah East Levee (near Myall Creek) being overtopped during the 1% AEP flood which contributes a significant additional volume of runoff to the CBD and East Murwillumbah. More specifically, peak 1% AEP depths across the CBD are predicted to be around 3 metres higher than peak 5% AEP depths, while across East Murwillumbah the differences are commonly more than 1 metre.

3.3.2 Low River Level Scenario

The results presented in the previous section assumed flooding behind each levee was occurring in conjunction with riverine flooding. When elevated water levels occur within the river system, it impedes the ability for the local stormwater system to drain under gravity into the river. Therefore, the base design flood results do not provide a complete picture of the performance of the stormwater system as the predicted inundation depths may not be associated with a lack of stormwater capacity, but elevated river levels.

To gain a better understanding of the capacity of the existing stormwater system in isolation, additional design flood simulations were completed assuming 'non flood' conditions within the river. This involved re-simulating the critical local catchment design storms with a low river water level of -0.4 mAHD (i.e., an approximate low tide level).

Peak water depths were extracted from the results of the revised design flood simulations and are presented in **Figures 7**, **8** and **9** for the 20% AEP, 5% AEP and 1% AEP floods respectively.

Flood level difference mapping was also prepared to show the location and magnitude of changes in water level and extent under the low river level scenario relative to the base design flood level results documented in the previous section. The difference mapping is provided in **Appendix D**.

Figures 7, **8** and **9** and the difference mapping in **Appendix D** shows that reducing the river level does reduce water depths and extents behind the levee system. More specifically:

- 20% AEP flood levels across the Murwillumbah CBD are typically 0.2 to 0.8 metres lower. The most significant reductions are within Lavender Creek (i.e., >2 metres difference). Across East Murwillumbah, the most significant (i.e., >0.6 metres) flood level reduction are contained to areas of open space although reductions of around 0.2 metres are predicted to extend into some residential areas.
- 5% AEP flood levels across the CBD are typically 0.2 to 0.6 metres lower (again, reductions of more than 2 metres are predicted in Lavender Creek). Across East Murwillumbah, the reductions in 5% AEP levels are broadly similar to the 20% AEP event.
- 1% AEP flood levels across the CBD and East Murwillumbah are predicted to reduce significantly (i.e., >3 metres and >1.5 metres respectively). However, much of this difference is associated with the Commercial Road and East Murwillumbah levees not overtopping during the low river level scenario rather than a significant improvement in drainage efficiency.

Therefore, elevated water levels within the river system do inhibit the performance of the stormwater system, thereby resulting in higher flood levels for some areas contained behind the levee system.

Stormwater Capacity

The results of the base design flood simulations and the low river level simulations were also reviewed to understand:

- which sections of the stormwater system are/are not impacted by elevated water levels?
- How the nominal capacity of the stormwater system changes under low versus elevated river levels?

The outcomes of this assessment are presented in **Figure 10** and **Figure 11**.

Figure 10 and **Figure 11** shows that the stormwater system in the more elevated sections of Murwillumbah is not impacted by the river levels and has a nominal capacity of a 1% AEP flood (this capacity is likely overstated due to the relatively course model grid size versus stormwater inlet sizes).

Much of the stormwater system that is contained to lower-lying areas has a nominal capacity of less than a 20% AEP flood. Therefore, although it is highly probable that elevated river levels impact on the performance of the pipe system in these areas, the existing pipe system has insufficient capacity to convey a 20% AEP flood even under a low river level scenario.

However, several sections of the stormwater system do show significant improvement in stormwater capacity with a low river level. This includes sections of stormwater system contained within Proudfoots Lane, Main Street, Tumbulgum Road, Wollumbin Street, Brisbane Street, as well as Nullum Street. The stormwater system at these locations has a nominal capacity of a 20% AEP flood under elevated river levels which is predicted to improve to either a 5% AEP flood or a 1% AEP flood under low river levels.

Therefore, it is evident the capacity of the stormwater system is impacted by the prevailing water levels within the river system. However, flooding behind each levee most commonly occurs in conjunction with elevated water levels. Therefore, the assessment of the various pump upgrade options (documented in the following chapter) assumed elevated water levels within the river system to ensure a realistic, but conservative, understanding of flood behaviour behind the levee system was provided.

4 MITIGATION OPTION ASSESSMENT

4.1 Overview

As discussed, the focus of the current study was to assess the potential benefits of a range of potential pump upgrades for the Murwillumbah CBD and East Murwillumbah. A total of nine different pump upgrade scenarios were requested by Council for analysis. The details of each option are provided in **Table 3.**

The following sections describe the outcomes of the assessment of each option. This includes the predicted hydraulic benefits (i.e., reductions in flood levels) for each option and the associated reductions in flood damage costs for the design 20% AEP, 5% AEP and 1% AEP floods (the February-March 2022 flood was also simulated to understand how each option may have benefited the wider community during this event). Cost estimates for each option were also developed by Council to enable a benefit cost ratio to be established to provide insight into the financial viability of each option.

Flood level differences were also extracted at a selection of discreet locations to enable a more precise understanding of flood level reductions to be gained. The location where the differences were extracted is shown in **Plate 6** and the differences at each location during each flood are provided in **Table 4**, **Table 5**, **Table 6** and **Table 7**.

Plate 6 Flood Level Difference Locations

Table 3 Summary of Pump and Stormwater Upgrade Options

ID	Components				
	Pump	Stormwater System / Pump Outlet	Pump Well	Pump Operation Levels	Other
Lavender Creek					
LC1	New pump (1x Flygt P7125) with capacity of 4m³/s	Existing outlet retained	N/A	Activate = 1.5 m AHD Deactivate = 1.0 mAHD	Relocate pump intakes off stormwater inlets. Construct new intake wells with screens. Improve debris screening and maintenance access.
LC2	New pumps (2x Flygt P7125) with capacity of 8m³/s				
LC3	New pumps (3x Flygt P7125) with capacity of 12m³/s	New outlet pipes			
Wharf Street					
WS1	Existing pump retained (capacity 0.2m³/s)	Upgrade existing 450mm dia offtake to 900mm offtake and upgrade stormwater pits	Larger pump well with direct inlet and outlet pipes	Existing pump activation levels retained	
WS2	New pump (1x Flygt P7065) with capacity of 1.2m³/s	As above with larger 800mm dia outlet pipe			
WS3	New pump (1x Flygt P7065) with capacity of 1.2m³/s	New pump connected into existing stormwater system	Contained in existing pit within Tumbulgum Road	Activate = 1.2 m AHD Deactivate = 1.0 mAHD	New pump to be placed approximately 85m north along Tumbulgum Road from existing pump well connecting to existing stormwater pipe outlet.
WS4	New pump (1x Flygt P7105) with capacity of 2.5m³/s	New pump connected into existing stormwater system			As above
King Street					
KS1	New pump (1x Flygt P7065) with capacity of 2.5m³/s	New pit to house pump system connecting to 1200mm dia outlet pipe	New well with 150m³ storage	Activate = 2.0 m AHD Deactivate = 1.5 mAHD	
East Murwillumbah					
EM1	New pump with capacity of 1.4m³/s (like existing Lavender Creek pump)	Pump to discharge to existing creek on northern side of George St	N/A	Activate =3.0 m AHD Deactivate = 2.5 mAHD	
EM2	As above	Upgraded stormwater along Reynolds Street			Additional open channels between Tumbulgum Road and Mayal Creek with a 600mm dia culvert under Tumbulgum Road.
Combined Option					
CO1	LC2 with WS4, as detailed above				

Table 4 20% AEP Flood Level Reductions at Key Locations for Each Option

ID	Option										
	Lavender Creek			Wharf Street				King St	East Murbah		Combined
	LC1	LC2	LC3	WS1	WS2	WS3	WS4	KS1	EM1	EM2	CO1
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.45	-0.45	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.09	-0.09	0.00
4	0.00	0.00	0.00	0.00	-0.33	-0.31	-0.54	0.00	0.00	0.00	-0.54
5	0.00	0.00	0.00	0.00	-0.08	-0.11	-0.27	0.00	0.00	0.00	-0.27
6	-0.07	-0.07	-0.07	0.00	-0.07	-0.08	-0.11	-0.08	0.00	0.00	-0.13
7	-0.08	-0.08	-0.08	0.00	-0.08	-0.10	-0.14	-0.10	0.00	0.00	-0.52
8	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.03	-0.15	0.00	0.00	-0.03
9	-0.09	-0.09	-0.09	0.00	-0.07	-0.08	-0.11	-0.09	0.00	0.00	-0.25
10	-1.00	-1.22	-1.41	0.01	-0.08	-0.11	-0.16	-0.12	0.00	0.00	-1.21
11	-0.34	-0.34	-0.34	0.00	-0.14	-0.15	-0.18	-0.17	0.00	-0.01	-0.34
12	-0.20	-0.20	-0.20	0.00	-0.14	-0.15	-0.17	-0.17	0.00	-0.01	-0.20
13	-1.00	-1.19	-1.33	0.00	-0.08	-0.10	-0.16	-0.13	0.00	0.00	-1.20

Table 5 5% AEP Flood Level Reductions at Key Locations for Each Option

ID	Option										
	Lavender Creek			Wharf Street				King St	East Murbah		Combined
	LC1	LC2	LC3	WS1	WS2	WS3	WS4	KS1	EM1	EM2	CO1
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.51	-0.45	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.27	-0.27	0.00
4	0.00	0.00	0.00	0.00	-0.07	-0.06	-0.12	0.00	0.00	0.00	-0.12
5	0.00	0.00	0.00	0.00	-0.04	-0.05	-0.18	0.00	0.00	0.00	-0.18
6	-0.05	-0.06	-0.06	0.00	-0.04	-0.05	-0.11	-0.05	0.00	0.00	-0.22
7	-0.06	-0.06	-0.06	0.00	-0.05	-0.06	-0.11	-0.06	0.00	0.00	-0.26
8	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.22	0.00	0.00	-0.02
9	-0.07	-0.08	-0.08	0.00	-0.05	-0.06	-0.11	-0.06	0.00	0.00	-0.25
10	-0.25	-0.93	-0.93	0.00	-0.06	-0.07	-0.13	-0.08	0.00	0.00	-1.33
11	-0.29	-0.34	-0.34	0.00	-0.07	-0.08	-0.14	-0.09	0.00	-0.01	-0.40
12	-0.29	-0.34	-0.34	0.00	-0.07	-0.08	-0.14	-0.09	0.00	-0.01	-0.38
13	-0.35	-1.19	-1.21	0.00	-0.06	-0.07	-0.12	-0.08	0.00	0.00	-1.30

Table 6 1% AEP Flood Level Reductions at Key Locations for Each Option

ID	Option										
	Lavender Creek			Wharf Street				King St	East Murbah		Combined
	LC1	LC2	LC3	WS1	WS2	WS3	WS4	KS1	EM1	EM2	CO1
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.50	-0.42	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.49	-0.42	0.00
4	0.00	0.00	0.00	0.00	-0.05	-0.02	-0.06	0.00	0.02	0.00	-0.06
5	0.00	0.00	0.00	0.00	-0.02	-0.01	-0.08	0.00	0.00	0.00	-0.08
6	-0.04	-0.06	-0.06	-0.01	-0.03	-0.02	-0.07	-0.05	0.01	0.00	-0.13
7	-0.04	-0.06	-0.06	-0.01	-0.03	-0.02	-0.07	-0.05	0.01	0.00	-0.14
8	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	-0.24	0.00	0.00	-0.01
9	-0.07	-0.09	-0.09	-0.01	-0.04	-0.04	-0.08	-0.07	0.01	-0.01	-0.17
10	-0.19	-0.76	-0.76	0.00	-0.04	-0.03	-0.09	-0.08	0.01	0.00	-0.96
11	-0.23	-0.36	-0.36	-0.01	-0.06	-0.05	-0.13	-0.12	0.01	-0.01	-0.42
12	-0.23	-0.36	-0.36	-0.01	-0.06	-0.05	-0.13	-0.12	0.01	-0.01	-0.42
13	-0.33	-1.29	-1.29	-0.02	-0.06	-0.05	-0.12	-0.11	0.01	-0.01	-1.44

Table 7 February/March 2022 Flood Level Reductions at Key Locations for Each Option

ID	Option										
	Lavender Creek			Wharf Street				King St	East Murbah		Combined
	LC1	LC2	LC3	WS1	WS2	WS3	WS4	KS1	EM1	EM2	CO1
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.26	-0.25	0.01
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.26	-0.25	0.01
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.26	-0.25	0.01
4	0.00	0.00	0.00	0.00	-0.06	-0.05	-0.10	0.00	0.00	0.00	-0.11
5	-0.21	-0.29	-0.30	0.00	-0.08	-0.09	-0.17	-0.12	0.00	-0.01	-0.26
6	-0.22	-0.35	-0.44	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.45
7	-0.22	-0.35	-0.44	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.45
8	-0.21	-0.35	-0.43	0.00	-0.08	-0.09	-0.17	-0.12	0.00	-0.01	-0.45
9	-0.22	-0.35	-0.44	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.45
10	-0.22	-0.35	-0.44	-0.01	-0.07	-0.09	-0.17	-0.13	0.00	-0.01	-0.46
11	-0.22	-0.35	-0.44	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.45
12	-0.22	-0.35	-0.44	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.45
13	-0.22	-0.36	-0.46	0.00	-0.08	-0.09	-0.18	-0.12	0.00	-0.01	-0.46

An economic assessment of each pump option was also completed. This was completed by undertaking a revised flood damage assessment with each pump option in place. This allowed the reduction in flood damage costs afforded by each option to be compared against the total cost of each option, which is summarised in **Table 8**. This, in turn, allowed a benefit cost ratio to be calculated (also included in **Table 8**).

Table 8 Financial benefits and costs for each option

Option	Present Value of Costs and Damages ($ Millions)			Benefit-Cost Ratio
	Net Present Value of Damages	Reduction in Damage with Option in Place	Cost	
Existing	37.16	N/A	N/A	N/A
Lavender Creek Pump Upgrades				
LC1	35.92	1.24	2.38	0.52
LC2	35.87	1.29	3.82	0.34
LC3	35.87	1.29	5.48	0.25
Wharf Street Pump Upgrades				
WS1	37.17	0.00	0.45	0.00
WS2	34.43	2.73	1.28	2.13
WS3	34.22	2.94	1.83	1.61
WS4	33.04	4.12	2.41	1.71
King Street Pump Upgrade				
KS1	35.79	1.36	2.13	0.64
East Murwillumbah Pump Upgrade				
EM1	36.91	0.24	1.21	0.20
EM2	36.36	0.80	2.18	0.37
Combined Option				
CO1	32.20	4.95	6.23	0.80

The benefits were calculated by accumulating the reduction in average annual damage over a 50-year period with each pump option in place based on a 7% discount rate. Similarly, the total cost of each pump option was accumulated over the same 50-year period based on the following components:

- Capital (i.e., “up front”) implementation costs for each option, as shown in **Appendix E**.
- Replacement of main pump unit(s) after 25-years (discounted to present value based on a 7% rate).
- Average annual maintenance costs of $2,500 per annum discounted over a 50-year period (a 7% discount rate was applied)

4.2 Lavender Creek Pump Upgrades

4.2.1 LC1

As noted in **Table 3**, this option would involve upgrading the existing Lavender Creek pump station to a nominal capacity of 4 m^3/s to drain Lavender Creek and the broader CBD 'basin' more efficiently. The existing pump outlets to the Tweed River would be retained. It is expected to have a life cycle cost of about $2.4 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of LC1 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how LC1 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 7**.

Plate 7 shows that LC1 is predicted to reduce existing flood levels across the CBD during all simulated design floods. This includes reductions of up to 0.2 metres near Elizabeth Street and Brisbane Street and reductions of up to 0.3 metres in Lavender Creek. More modest reductions are predicted across the northern parts of the CBD (i.e., less than 0.05 metres).

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of LC1 was predicted to reduce existing flood damages by approximately $1.2 million over the next 50 years. This yields a benefit cost ratio of about 0.5. Therefore, LC1 is the best performing Lavender Creek option from a benefit cost perspective. However, LC2 and LC3 provide greater overall flood damage reductions.

A 1% AEP stage hydrograph was also extracted for Lavender Creek immediately upstream of the pump to understand what improvements LC1 may afford with respect to the time variation in water levels across the CBD. This hydrograph is provided in **Plate 8**.

The hydrographs show that LC1 is effective in keeping water levels below 2 mAHD for an extended period of time. This would ensure that local roads in the vicinity of Lavender Creek would remain open for around 35 hours longer than the current pump would allow. It is also evident that LC1 will draw down water levels much more rapidly which would allow clean up efforts to commence sooner (the water level would drop below 2 mAHD around 10 hours quicker than the current pump). However, **Plate 8** also shows that the LC1 pump becomes overwhelmed during the most intense downpour resulting in water levels approaching 3 mAHD.

Overall, LC1 is predicted to provide a notable improvement over the existing pump and the best benefit cost ratio of the Lavender Creek pump upgrade options. If funding permits, LC2 is the preferred option as it provides greater overall damage reductions and improved emergency response benefits. However, if sufficient funding cannot be secured for LC2, LC1 should be considered for implementation.

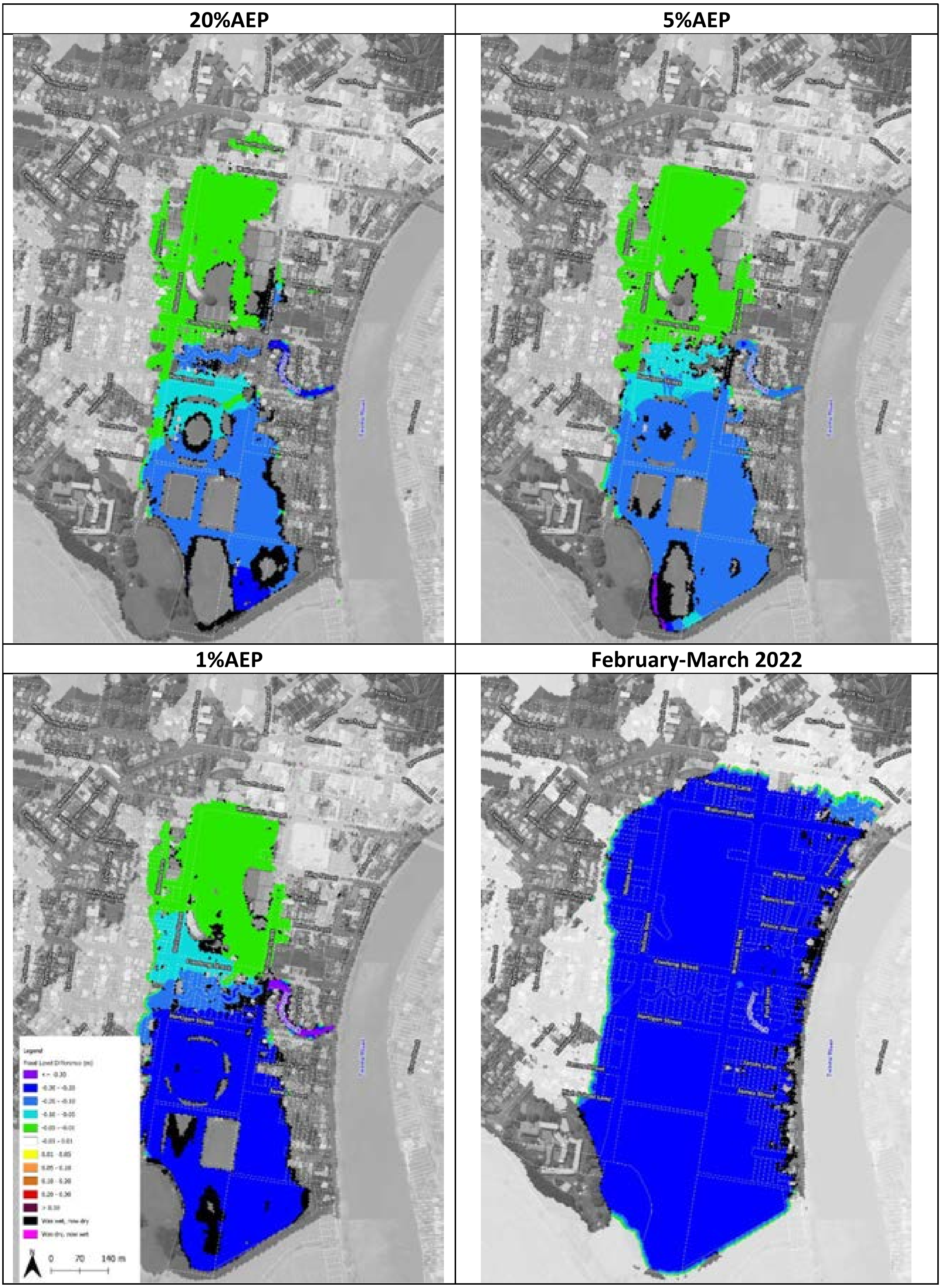


Plate 7 Flood Level Difference Map for LC1

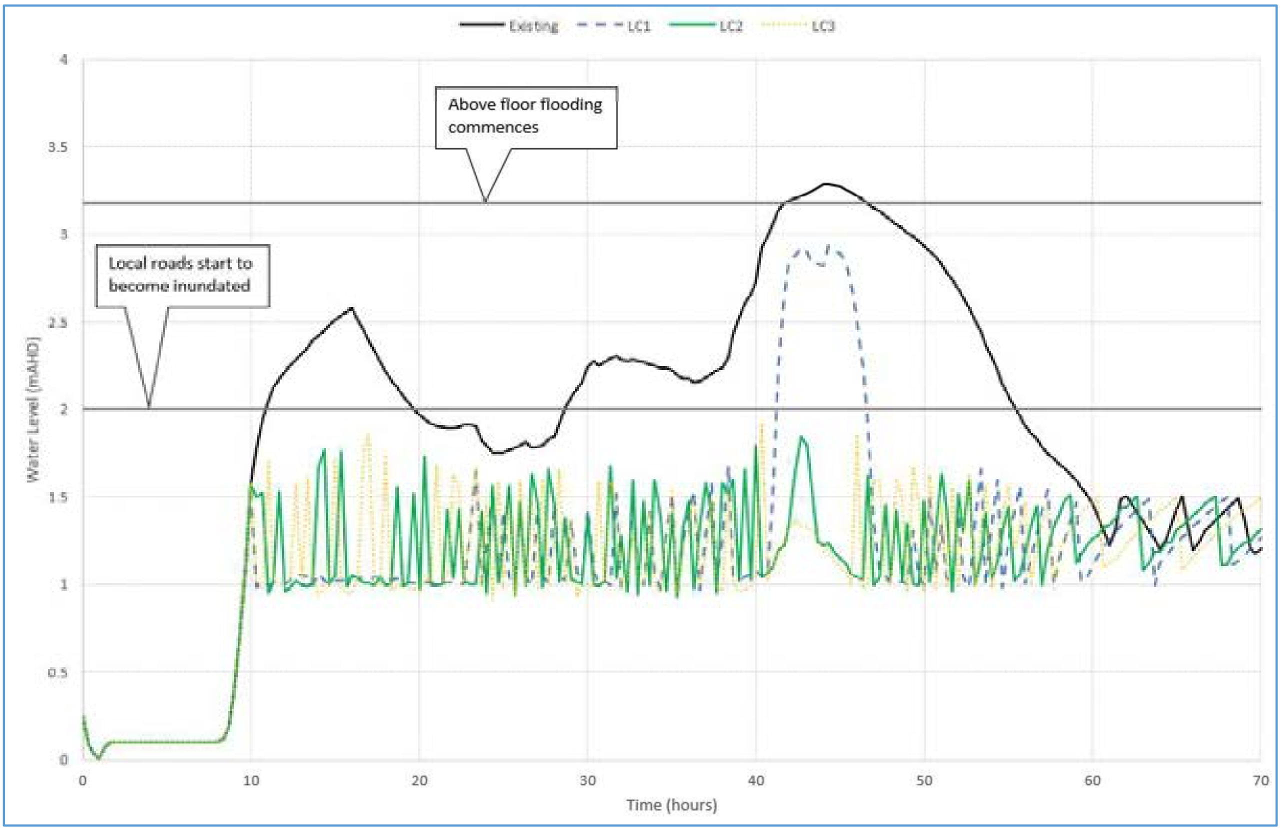


Plate 8 1% AEP stage hydrograph for LC options

4.2.2 LC2

This option would involve upgrading the exiting Lavender Creek pump station to a nominal capacity of 8 m^3/s (i.e., double the peak flow rate of LC1). It is expected to have a life cycle cost of about $3.8 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of LC2 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how LC2 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 9.**

Plate 9 shows that LC2 is predicted to reduce existing flood levels across the CBD during all simulated design floods as well as the March 2022 event. This includes reductions of up to 0.4 metres during the 20% AEP near Brisbane Street and more than 1 metre in Lavender Creek during the 1% AEP flood. Flood level reductions across the northern parts of the CBD are generally less than 0.1 metres.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of LC2 was predicted to reduce existing flood damages by nearly $1.3 million over the next 50 years. This affords a benefit cost ratio of 0.34. Therefore, although the benefit cost ratio is not as high as LC1, the overall damage reductions are greater than LC1 and equivalent to LC3.

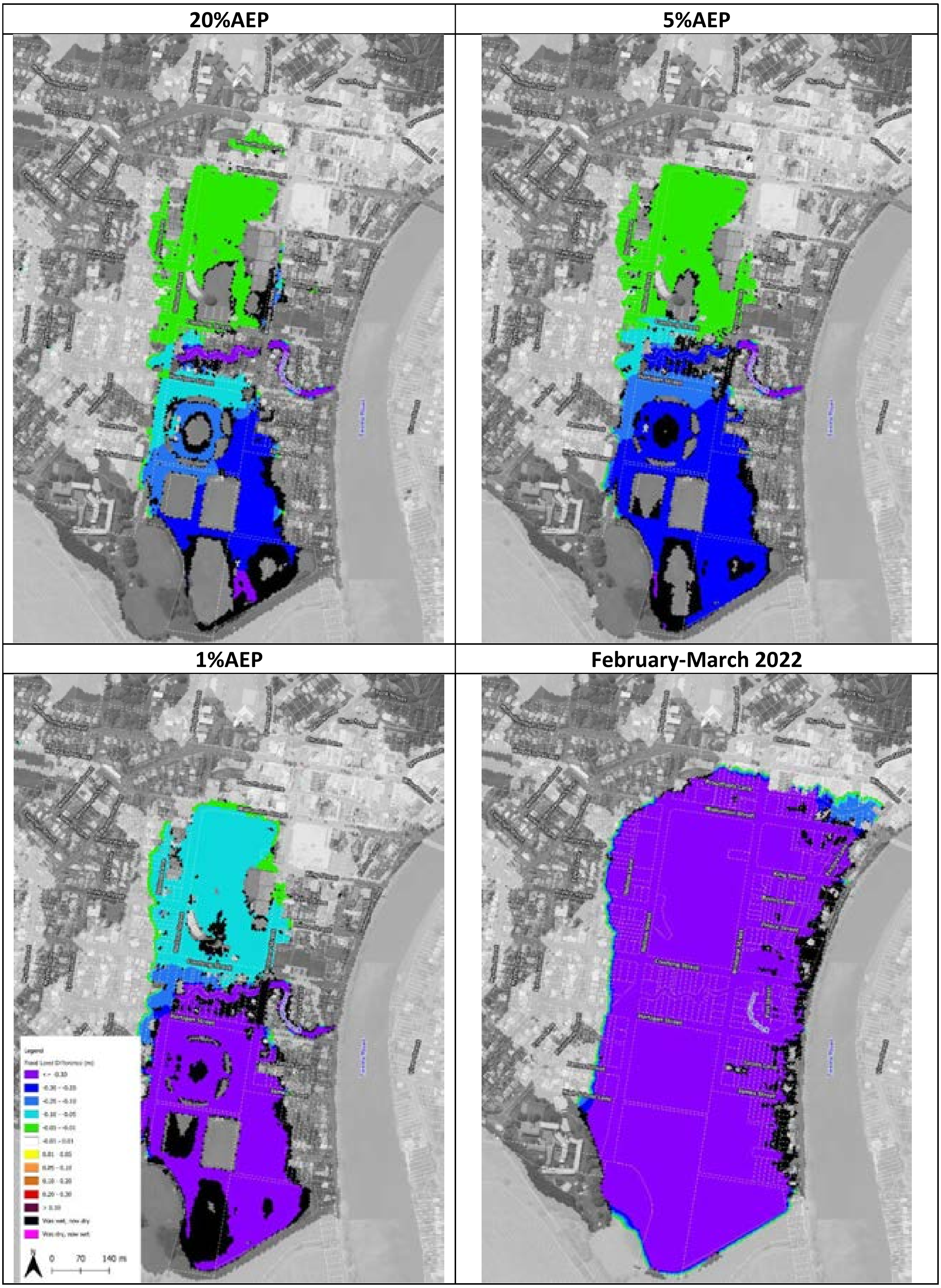


Plate 9 Flood Level Difference Map for LC2

A 1% AEP stage hydrograph at Lavender Creek was extracted for LC2 and is provided in **Plate 8**. It shows that LC2 provides similar performance to LC1 across much of the event. However, the additional capacity afforded by LC2 is predicted to keep water levels below 2 mAHD for the full duration of the 1% AEP flood. Therefore, LC2 provides an improved outcome relative to LC1 in terms of reducing the potential for flooding of local roads and above floor flooding near to Lavender Creek. Furthermore, the performance of LC2 is similar to the more expensive LC3.

Overall, LC2 provides greater flood level reductions and flood damage reductions as LC1 and provides roughly equivalent performance as LC3. Although more expensive than LC1, it is considered that LC2 should be pursued as the preferred option as it provides the best overall benefit to wider community.

4.2.3 LC3

As noted in **Table 3**, this option would involve upgrading the exiting Lavender Creek pump station to a nominal capacity of 12 m^3/s (i.e., three times the capacity of LC1). This additional outflow capacity will also require upgrading of the existing pump outlets. As a result, LC3 is expected to be the most expensive of the Lavender Creek pump upgrade options with a life cycle cost of about $5.5 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of LC3 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how LC3 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 10.**

Plate 10 shows that, despite the additional pump capacity LC3 is predicted to provide similar flood level reductions to LC2. A review of the flood model results determined that the pump was very rarely operating at full capacity during each of the design flood simulations. Further interrogation of the results determined this was because of insufficient local drainage capacity to “deliver” 12 m^3/s from the CBD catchment to the upgraded pump. That is, to better utilise the available pump capacity, it is likely that extensive upgrades to the stormwater and culvert system would be required.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of LC3 was predicted to reduce existing flood damages by about $1.3 million over the next 50 years. This yields a benefit cost ratio of 0.25. The total reduction in flood damages is similar to LC2. This confirms that the additional capacity of LC3 is not yielding a significant improvement in hydraulic performance relative to LC2.

A 1% AEP stage hydrograph at Lavender Creek was extracted for LC3 and is provided in **Plate 8**. It shows similar performance relative to LC2 across the full duration of the 1% AEP flood. This again provides evidence that the additional capacity of LC3 is not being fully utilised (i.e., both LC1 and LC2 afford better benefit-cost performance).

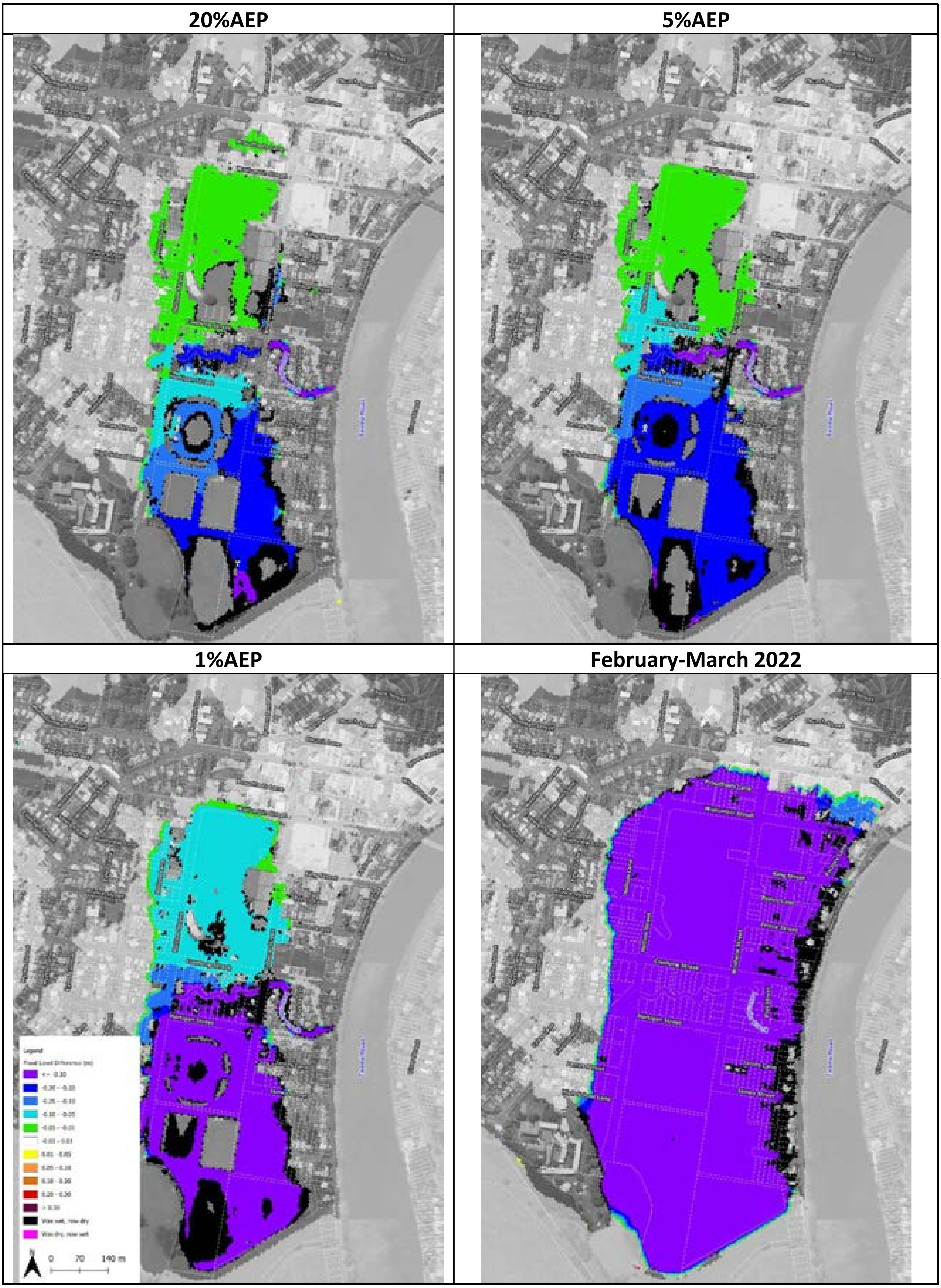


Plate 10 Flood Level Difference Map for LC3

Although LC3 is predicted to afford notable flood level reductions and reductions in flood damage costs, they are predicted to be roughly equivalent to LC2. As LC2 is considerably cheaper to implement, it is recommended that LC2 is implemented in preference to LC3.

4.3 Wharf Street Pump Upgrades

4.3.1 WS1

This option would involve upgrading the existing Wharf Street pump well and inlet/outlet pipes to provide a more direct pump system. It is expected to have a life cycle cost of about $450,000 (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of WS1 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how WS1 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 11.**

Plate 11 shows that WS1 is predicted to afford no reductions during most of the simulated design floods. Only the 1% AEP event saw a modest reduction across the southern parts of the CBD (i.e., less than 0.05 metres).

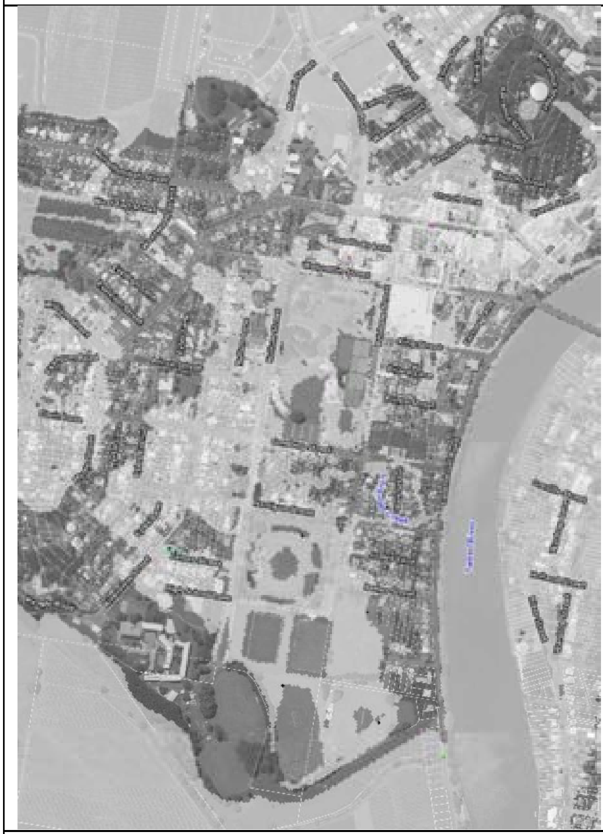
A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of WS1 was not predicted to produce any notable flood damage reductions and yielded a benefit cost ratio of 0. Therefore, there is little hydraulic and economic incentive to pursue Option WS1 particularly considering the much better performing WS2, WS3 and WS4.

4.3.2 WS2

As shown in **Table 3**, this option would involve upgrading the existing Wharf Street pump well and inlet/outlet pipes and pump to a nominal capacity of 1.2 m^3/s (i.e., a fivefold increase in capacity relative to the existing pump). It is expected that WS2 will have a life cycle cost of about $1.3 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of WS2 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how WS2 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 12.**

Plate 12 shows that WS2 is predicted to reduce existing flood levels across the CBD during all simulated design floods. The most significant flood level reductions of more than 0.3 metres are predicted in Wharf Street during the 20% AEP flood. However, flood level reductions of more than 0.1 metres are also predicted to extend to the southern sections of the CBD basin.

20%AEP	5%AEP
	

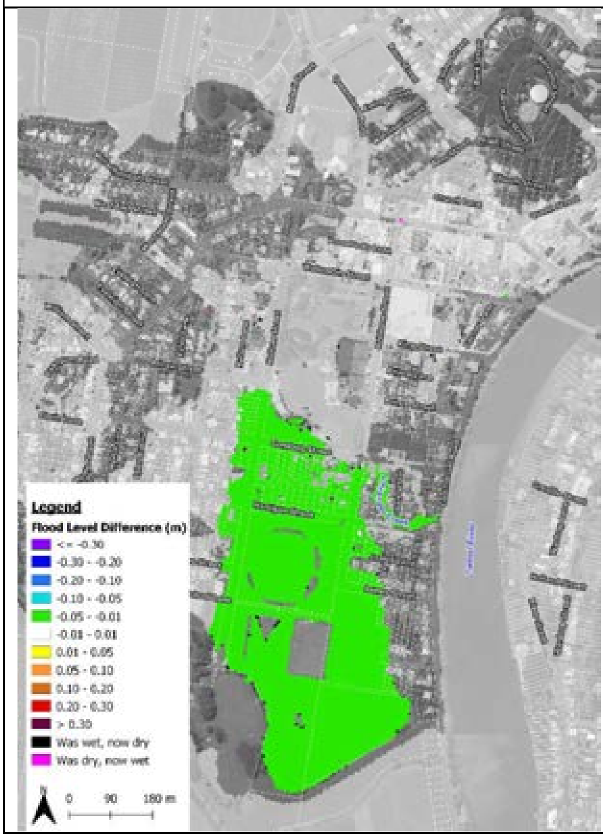
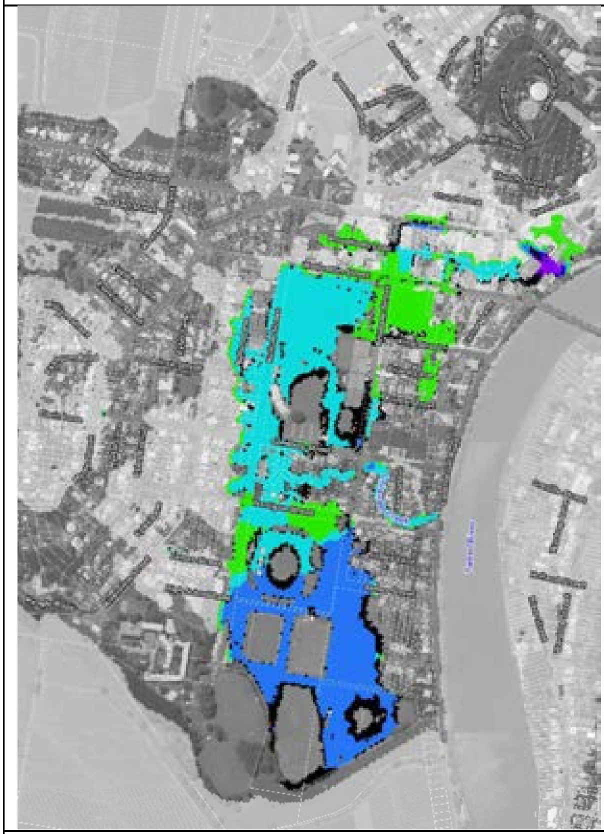
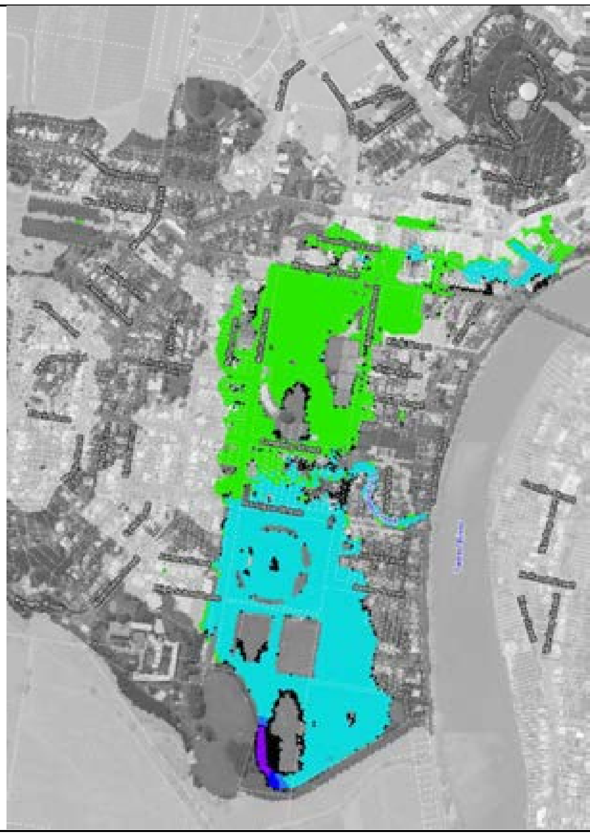
1%AEP	February-March 2022
	

Plate 11 Flood Level Difference Map for WS1

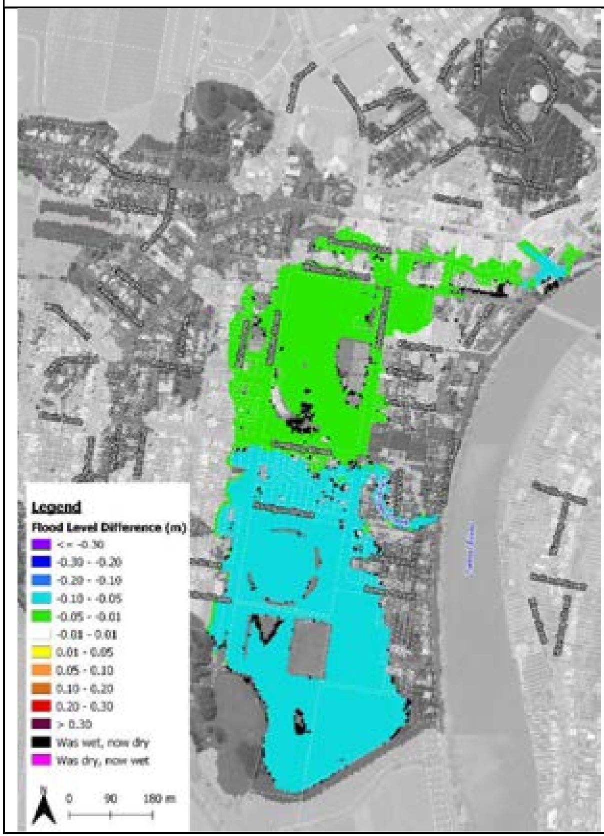
20%AEP



5%AEP



1%AEP



February-March 2022

Plate 12 Flood Level Difference Map for WS2

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of WS2 was predicted to reduce existing flood damages by about $2.73 million over the next 50 years. This yields a benefit cost ratio of 2.13. Therefore, WS2 provides the best benefit cost ratio of not only the Wharf Street options but all options considered as part of this assessment.

WS2 will also assist in draining the area behind the levee more rapidly. However, the pump does not have direct access to the stormwater system draining the lowest point in the CBD "basin". As a result, it will not drain the area behind the levee as effectively as the Lavender Creek upgrade options. Nevertheless, the commercial areas of Murwillumbah will benefit from less frequent inundation and clean-up cost which will reduce the potential impacts of flooding on the local economy.

Overall, WS2 is predicted to provide the best benefit cost ratio and could be considered for implementation. However, if funding permits, WS4 is the preferred option for the Wharf Street area as it provides greater overall damage reductions. However, if sufficient funding cannot be secured for WS4, WS2 should be considered for implementation.

4.3.3 WS3

This option would involve adding an additional pump with a nominal capacity of 1.2 m^3/s approximately 85m north along Tumbulgum Road from the existing Wharf Street pump well. This would aim to utilise the flow carrying and storage capacity within the existing trunk drainage system. This provides a total pump capacity of about 1.4 m^3/s when combined with the existing Wharf Street pump. It is expected that WS3 would have a life cycle cost of about $1.8 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of WS3 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how WS3 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 13.**

Plate 13 shows that WS3 affords similar flood level reductions relative to WS2. This includes reductions of around 0.3 metres in Wharf Street during the 20% AEP flood and reductions of more than 0.5 metres during the 5% AEP flood and reductions of around 0.1 metres during the 1% AEP flood across the CBD 'basin'.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of WS3 was predicted to reduce existing flood damages by about $2.9 million over the next 50 years. This provides a benefit cost ratio of more than 1.6 indicating the reduction in flood damage costs is more than sufficient to offset the implementation costs.

Although WS3 provides an excellent benefit cost ratio, WS4 is predicted to provide much great overall flood damage reductions and an improved benefit cost ratio. Therefore, it is recommended that WS4 is pursued in preference to WS3.

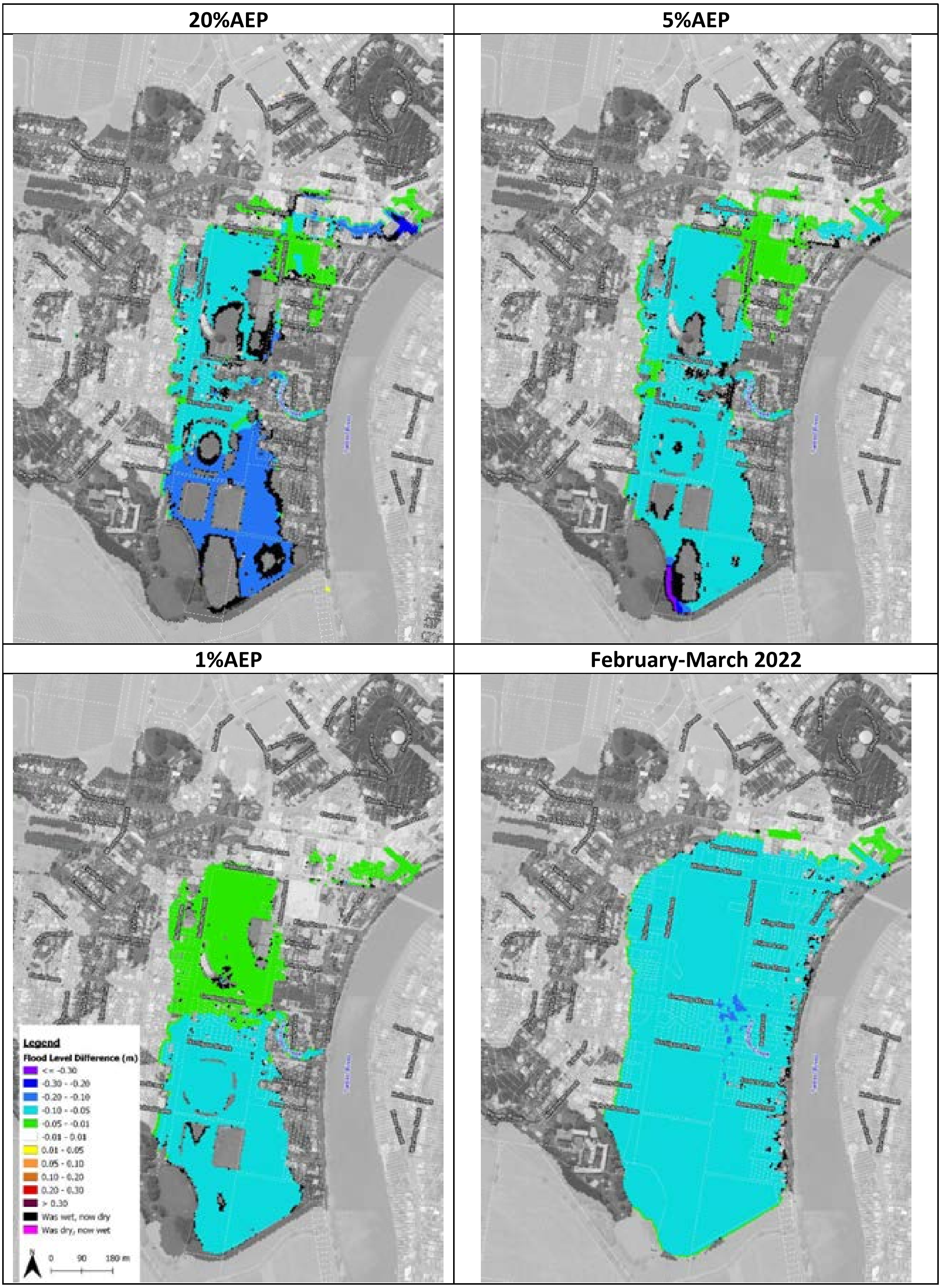


Plate 13 Flood Level Difference Map for WS3

4.3.4 WS4

WS4 would involve installing a new pump within the existing trunk drainage along Tumbulgum Road. Therefore, this option is similar to WS3, however, the new pump would provide a nominal capacity of 2.5 m^3/s (i.e., more than double the capacity of WS3). It is expected to have a life cycle cost of about $2.4 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of WS4 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how WS4 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 14.**

Plate 14 shows that WS4 is predicted to provide the most substantial flood level reduction in Wharf Street of all options considered (i.e., around 0.5 metres during the 20% AEP flood). Significant flood level reductions are also predicted during the 5% AEP flood in Wharf Street and Proudfoots lane (i.e., >0.2 metres) as well as the southern sections of the CBD basin (i.e., >0.6 metres). Therefore, the hydraulic benefits of WS4 are significant.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8.** This showed implementation of WS4 was predicted to reduce existing flood damages by more than $4 million over the next 50 years. This yields a benefit cost ratio of about 1.7.

Although WS4 is the most expensive Wharf Street pump upgrade option, it is also predicted to be the best performing from a flood level reductions and flood damage cost reductions perspective. Therefore, if funding permits, WS4 is the preferred pump upgrade options for the Wharf Street area. If sufficient funding cannot be secured for WS4, WS2 could be pursued.

4.4 King Street Pump

4.4.1 KS1

As noted in **Table 3**, KS1 would involve installing a new pump and pump well at the intersection of King Street and Commercial Road. This option would look to utilise the existing stormwater system draining from Knox Park to the Tweed River via King Street. The new pump would have a nominal capacity of 2.5 m^3/s. It is expected to have a life cycle cost of about $2 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of KS1 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how KS1 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 15.**

Plate 15 shows that KS1 is predicted to reduce existing flood levels across the CBD during all simulated design floods. The most significant flood level reductions of >0.2 metres are predicted alongside King Street during the 20% AEP flood. However, flood level reductions of more than 0.1 metres are predicted across most of the CBD basin during each design flood as well as the March 2022 flood.

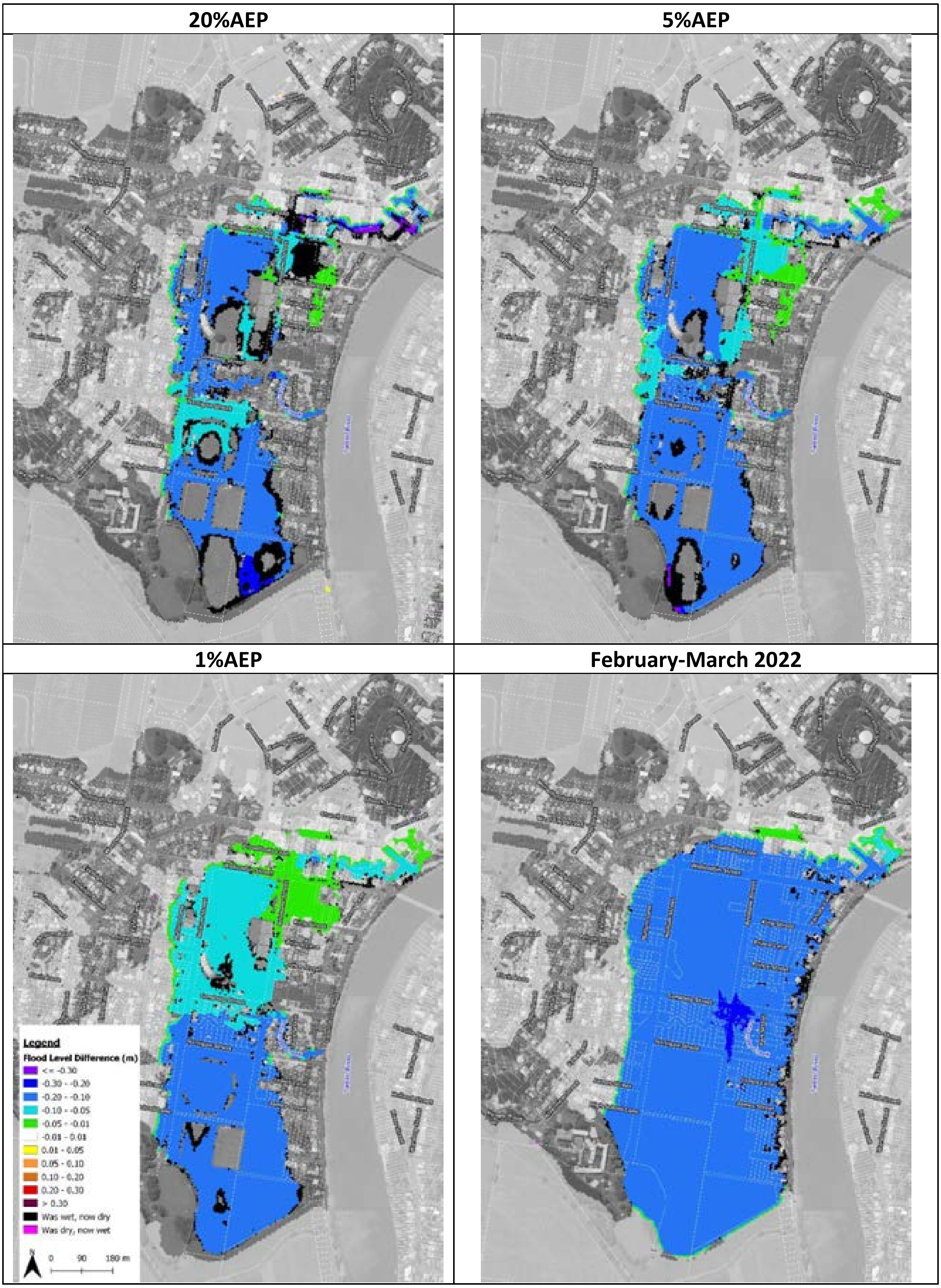
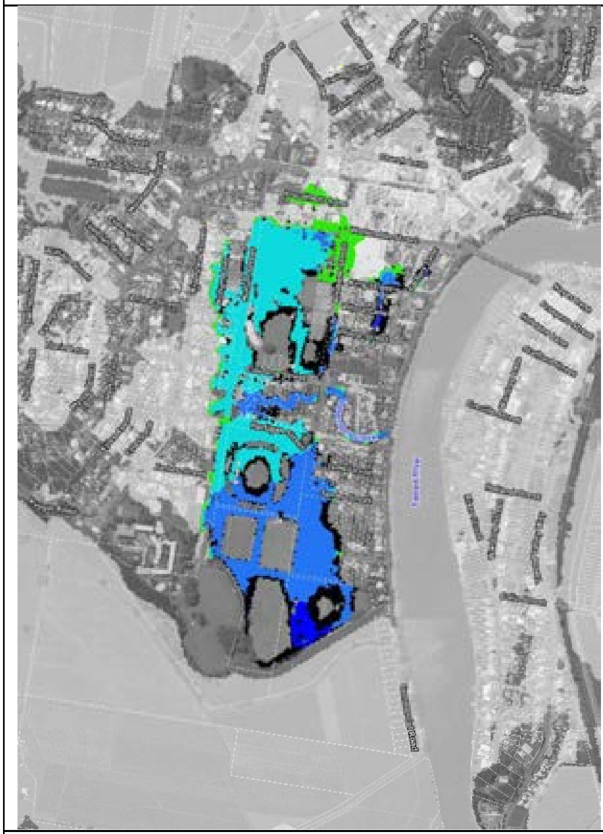
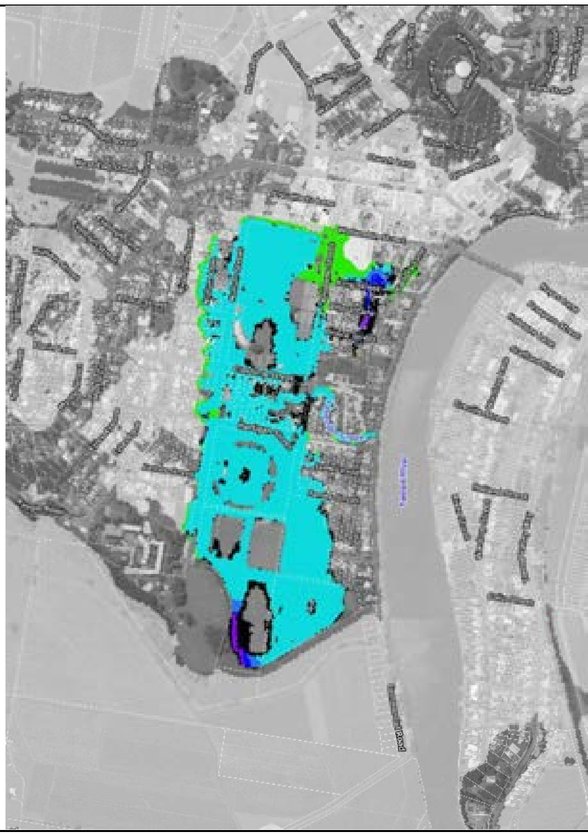


Plate 14 Flood Level Difference Map for WS4

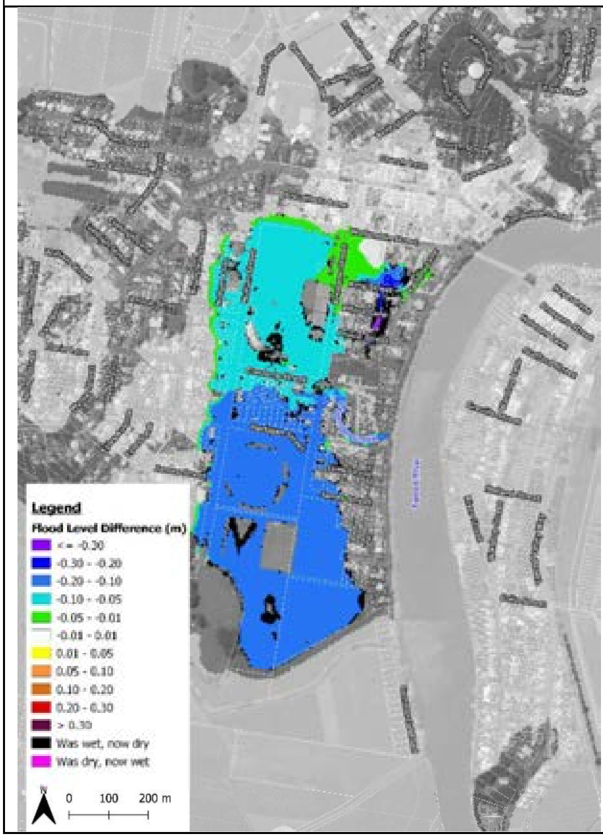
20%AEP



5%AEP



1%AEP



February-March 2022

Plate 15 Flood Level Difference Map for KS1

Although KS1 does not afford the same magnitude of flood level reductions as LC1, LC2 or LC3, it should be recognised that the capacity of KS1 is considerably lower. The more efficient hydraulic performance of KS1 is likely associated with the King Street pump option having a more direct access to the Knox Park area. Therefore, it is less susceptible to the limitations of the existing stormwater system draining to Lavender Creek.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8.** This showed implementation of KS1 was predicted to reduce existing flood damages by nearly $1.4 million over the next 50 years. This yields a benefit cost ratio 0.64. Therefore, KS1 provides about the same magnitude of flood damage reductions as LC1, LC2 or LC3 for a lower implementation cost. Much of this performance is associated with additional flood level reductions provided along King Street.

Overall, KS1 is predicted to produce reductions in flood levels and flood damage costs. LC2 provides slightly better hydraulic performance relative to KS1. Therefore, LC2 is recommended for implementation in front of KS1. However, KS1 could be considered as an alternative to the Lavender Creek options should any technical of financial impediments appear or could be considered as a supplementary measure to LC2 to further improve the hydraulic benefits across the CBD basin.

4.5 East Murwillumbah Pump

4.5.1 EM1

As shown in **Table 3**, this option would involve installing a new pump near the East Murwillumbah levee on George Street. The pump would have a nominal capacity of 1.4 m^3/s. It is expected to have a life cycle cost of about $1.2 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of EM1 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how EM1 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 16.**

Plate 16 shows that EM1 is predicted to reduce existing flood levels across East Murwillumbah by around 0.5 metres during all simulated design floods. It is also predicted to provide reductions approaching 0.3 metres during the March 2022 flood. The less efficient performance during the March 2022 flood is associated with the levee overtopping during this event resulting in the new pump being overwhelmed. Although these flood level reductions are significant, most of the reductions are contained within open space to the south of George Street.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8.** This showed implementation of EM1 was predicted to reduce existing flood damages by about $240,000 over the next 50 years. This yields a benefit cost ratio of 0.2.

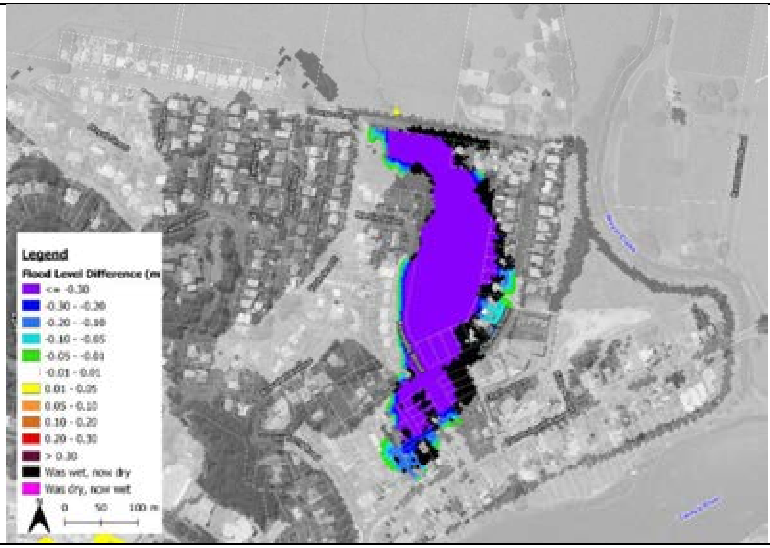
20%AEP	5%AEP
	
1%AEP	Feb_Mar2022
	

Plate 16 Flood Level Difference Map for EM1

A 1% AEP stage hydrograph was also extracted near George Street to understand what improvements EM1 may afford with respect to the time variation in water levels across East Murwillumbah. This hydrograph is provided in **Plate 8** and shows that the flood level reductions that are afforded would be sufficient for all local roads to remain trafficable during floods up to and including the 1% AEP event. It also shows that the duration of significant inundation (i.e., flood levels >3mAHD) would be reduced from around 30 hours to around 10 hours. Therefore, clean-up and recovery efforts could commence much sooner.

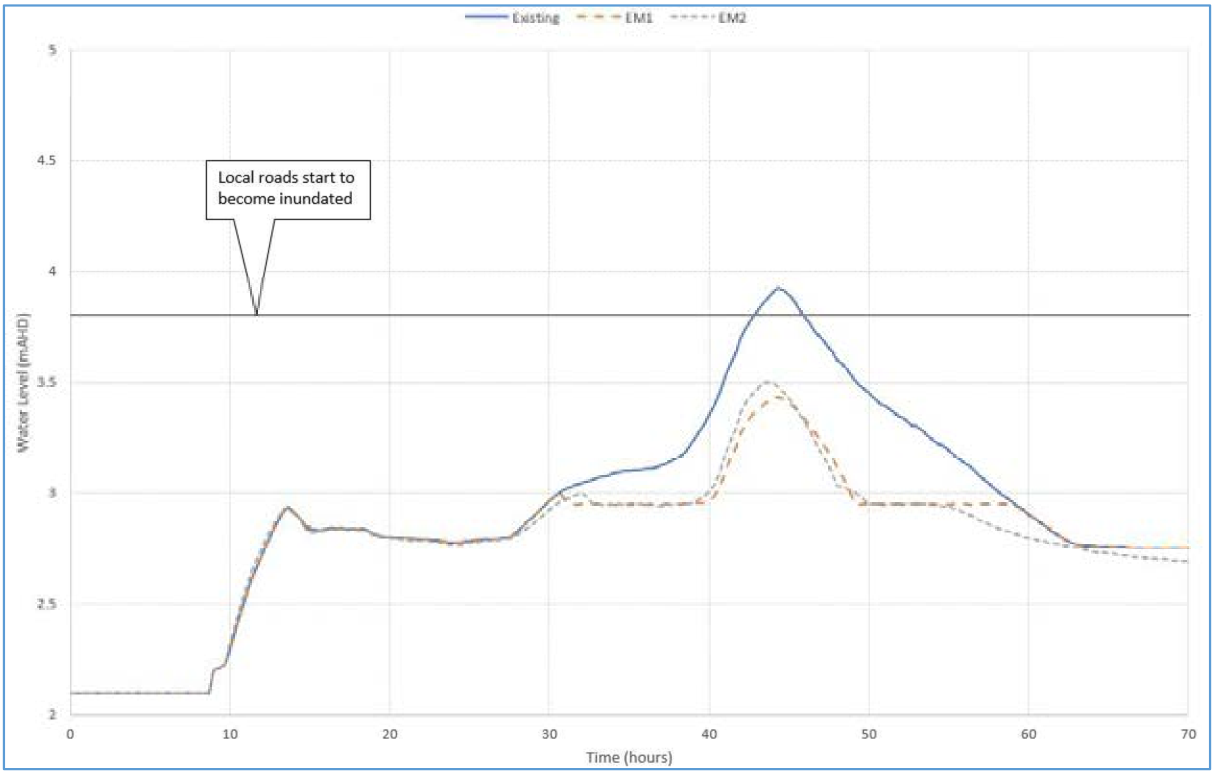


Plate 17 1% AEP stage hydrograph for EM options

EM1 provides some significant flood level reductions across East Murwillumbah. Although the flood level reductions primarily extend across open space and yield a relatively low benefit cost ratio, the reductions would have a range of emergency response benefits that cannot be quantified in monetary terms (i.e., increased potential for evacuation and less frequent incidences of the local community driving through floodwaters). Although it is recommended that the Lavender Creek and Wharf Street options are pursued in front of EM1, if additional funding can be secured, strong consideration should be given to implementing EM1.

4.5.2 EM2

EM2 would build upon EM1 by providing not only a new pump, but inclusion of stormwater upgrades along Charles Lane and Reynolds Street, a new culvert beneath Tumbulgum Road and a new open channel north of Tumbulgum Road. These drainage upgrades are intended to more efficiently direct flow from the broader East Murwillumbah area towards the new pump system. EM2 is expected to have a life cycle cost of about $2.2 million (refer cost estimates in **Appendix E**).

The TUFLOW model was updated to include a representation of EM2 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how EM2 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 18.**

Plate 18 shows that EM2 provides flood level reductions that are similar to EM1, particularly across the area immediately south of George Street. However, the additional drainage modifications are predicted to provide additional flood level reductions near Tumbulgum Road during the 5% AEP flood. Notwithstanding, the drainage modifications are predicted to increase existing flood levels on the northern side of Tumbulgum Road during the 20% AEP and 1% AEP floods. These increases are a result of the additional flow being directed from the southern side of Tumbulgum Road to this area.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of EM2 was predicted to reduce existing flood damages by about $800,000 over the next 50 years. This yields a benefit cost ratio of just under 0.4. Therefore, despite the additional implementation costs and the flood levels increases during the 20% AEP and 1% AEP floods, EM2 is predicted to provide a better economic outcome relative to EM1.

Although EM2 is predicted to afford a better economic outcome relative to EM1, EM2 is unlikely to gain funding support as it increases existing flood levels across some properties. Therefore, if funding allows, EM1 is the preferred pump option for East Murwillumbah.

4.6 Combined Options

4.6.1 CO1 (LC2 + WS4)

This option (CO1) looks at the combined benefit of implementing both LC2 and WS4. It is expected this combined option would have a total life cycle cost of about $6.2 million.

The TUFLOW model was updated to include a representation of CO1 and the updated model was used to re-simulate each design flood along with the February-March 2022 flood. Flood level difference maps were prepared to understand how CO1 was predicted to reduce existing flood levels and extents during each flood and these maps are provided in **Plate 19.**

Plate 19 shows that CO1 provides significant flood level reductions across the Murwillumbah CBD. This includes flood level reductions of at least 0.2 metres across most of the CBD basin during each design flood. During a March 2022 type flood, localised flood level reductions of more than 1 metre could be expected.

A revised flood damage assessment was completed based on the updated model results and the outcomes of this assessment are summarised in **Table 8**. This showed implementation of CO1 was predicted to reduce existing flood damages by nearly $5 million over the next 50 years. This yields a benefit cost ratio of 0.8.

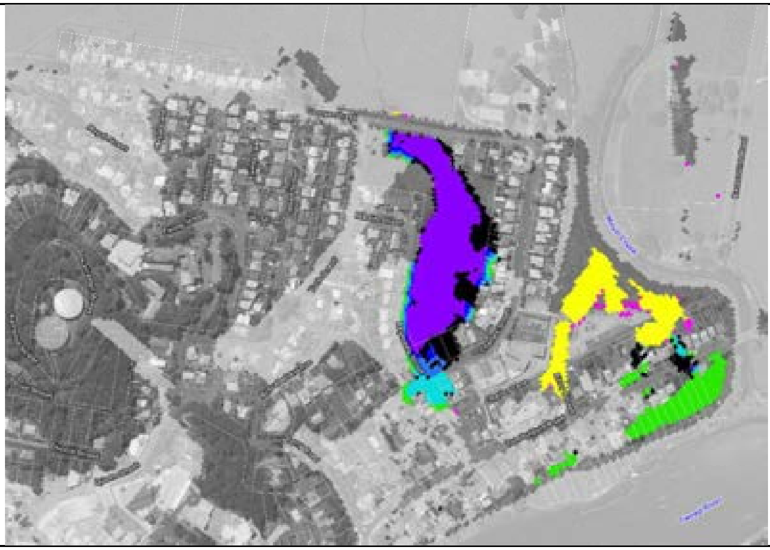
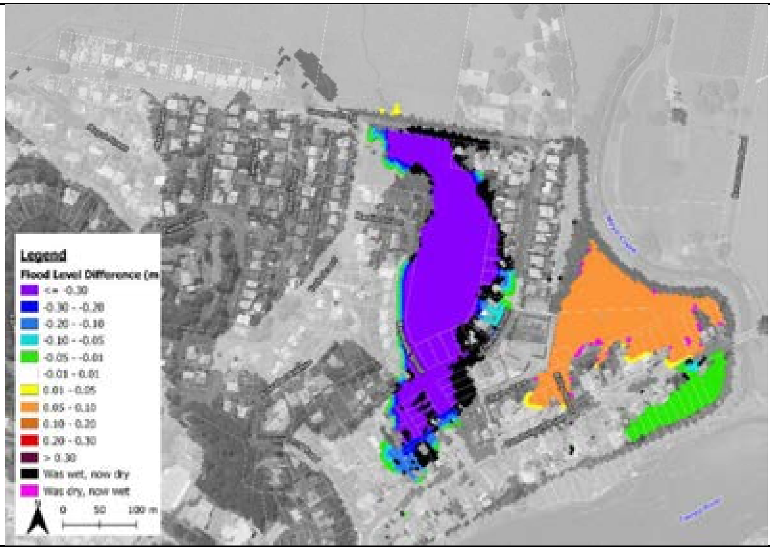
20%AEP	5%AEP
	
1%AEP	Feb_Mar2022
	

Plate 18 Flood Level Difference Map for EM2

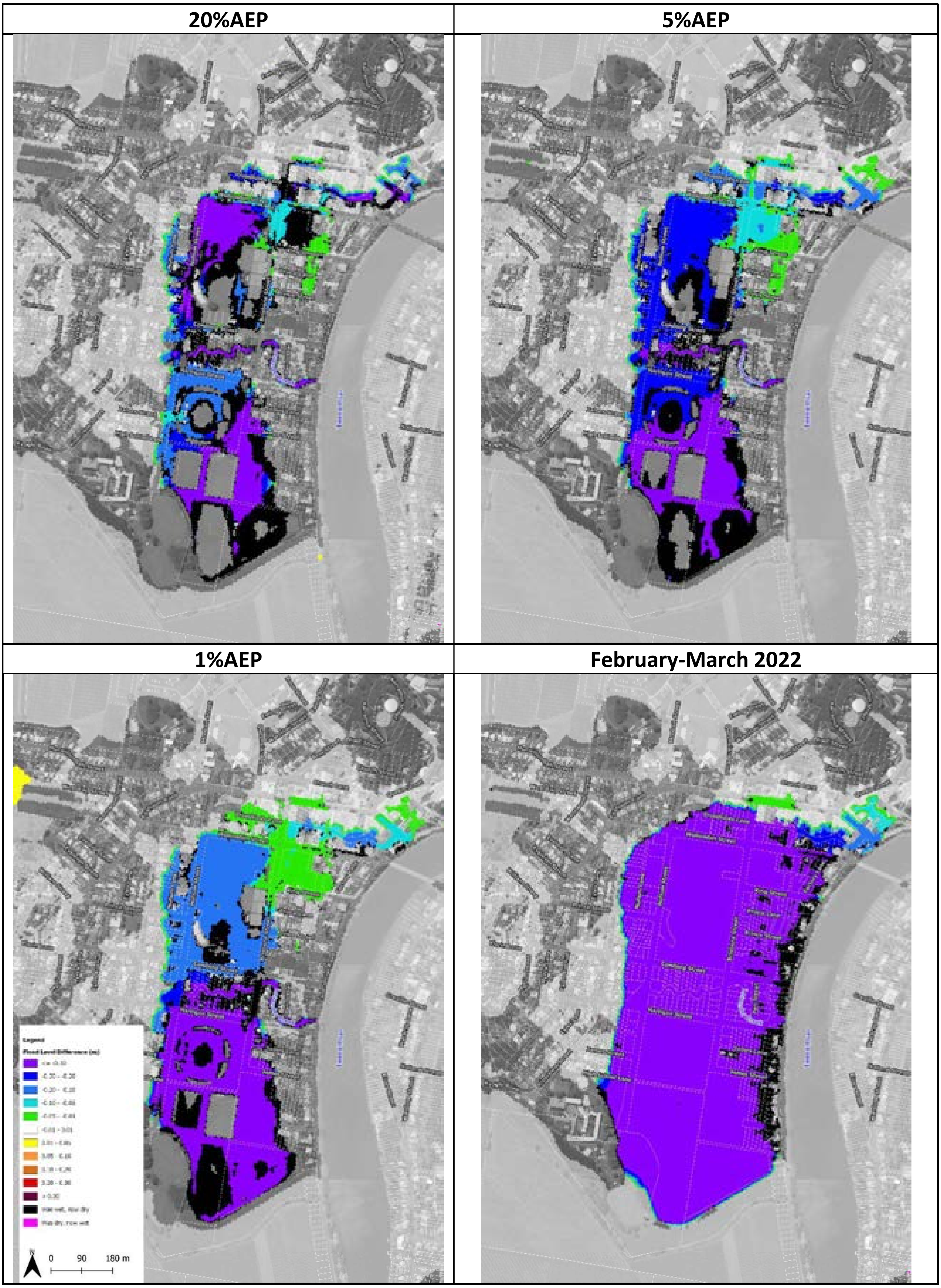


Plate 19 Flood Level Difference Map for CO1

CO1 would afford much the same non-monetary benefits as LC2 and WS4 in isolation. This includes less frequent flooding of the local road network (i.e., increased evacuation opportunities) and more rapid draining of the area contained behind the levee (i.e., clean up and recovery efforts could commence sooner). Therefore, implementation of LC2 and WS4 is highly recommended. As discussed in earlier sections of this report. Alternate Lavender Creek and Wharf Street options could also be considered for implementation if insufficient funding is available for CO1 (e.g., LC1 with WS2).

4.7 Recommendations

Based on the outcomes of the assessment of pump options presented in this chapter, the following options are considered to afford notable flood benefits and are considered to represent the best value for money (in isolation as well as when considered as a combined option):

- Lavender Creek: LC2
- Wharf Street: WS4

The King Street KS1 pump option also performed well and could be considered as an alternate to LC2.

Likewise, the East Murwillumbah EM1 pump options afforded notable flood level reductions. Although much of the flood level reduction extends across open space, several properties adjoining this space would also benefit. Therefore, the option could also be considered if funding permits. However, it is recommended that LC2 and WS4 are pursued in front of EM1.

If insufficient funding is available for LC2 and WS4, LC1 and WS2 could be pursued.

It should also be noted that the reliability of any pump system is highly dependent on a reliable power source. Therefore, it is recommended that any new pump system is supplemented with backup generators, where possible, to augment mains power.

5 CONCLUSION

This addendum report follows on from the *'Murwillumbah CBD Levee and Drainage Study'* (Catchment Simulation Solutions, 2018). It has documented the outcomes of the assessment of 10 pump upgrade options that could be potentially implemented to assist in better managing the flood risk from local rainfall/runoff behind the Murwillumbah CBD and East Murwillumbah Levees.

The potential pump upgrade options are distributed across 4 locations:

- Lavender Creek: 3 pump upgrade options
- Wharf Street: 4 pump upgrade options
- King Street: 1 pump upgrade option
- East Murwillumbah: 2 pump upgrade options

The assessment of the options was completed using a TUFLOW hydraulic model that was prepared as part of the 2018 study. However, surveyed flood levels that were collected following the March 2022 flood were used to validate the performance of the model before application to the pump upgrade options. This determined that the surveyed flood marks across the CBD were generally reproduced by the model to within 0.05 metres while the flood marks across East Murwillumbah were reproduced to within 0.1 metres.

The hydraulic model was updated to include a representation of each pump upgrade option and was used to simulate a range of design floods. This allowed the hydraulic performance of each option to be quantified and allowed an economic assessment of each option (in terms of predicted reductions in flood damage costs versus implementation costs).

Based on the outcomes of the assessment, the following pump upgrade options are considered to provide the best overall performance and are recommended for implementation:

- Lavender Creek: LC2
- Wharf Street: WS4

This would require an investment of more than $6 million over the next 50 years with most of that cost associated with the initial implementation. If full funding for the above options cannot be secured, the following options could be explored as a less capital-intensive pump upgrade option (this combined option would have a life cycle cost of about $3.7 million):

- Lavender Creek: LC1
- Wharf Street: WS2

The following options also afforded notable flood benefits and could be pursued if funding permits:

- King Street: KS1
- East Murwillumbah: EM1

It was also acknowledged that the reliability of any pump system is highly dependent on a reliable power source. Therefore, it is recommended that any new pump system is supplemented with backup generators, where possible, to augment mains power.

5.1 Public Exhibition

The draft *Addendum to the Murwillumbah CBD Levee & Drainage Study* was placed on public exhibition from 22 August 2023 until 20 September 2023.

A total of seven submissions were received. The submissions covered a range of topics. This included:

- General support for the recommended LC2 and WS4 options
- Acknowledgement that the existing levee system does not provide full protection across all possible floods.
- The need to provide an alternate power supply to the pumps to cater for electricity disruptions.
- The need to consider the flood risk outside of the Murwillumbah CBD
- The potential impacts of future population growth on the flood risk/flood damage calculations.

Each submission was reviewed and, where necessary, updates were completed to the draft report to address the submission. Those updates are reflected in this version of the report.

6 References

- Australian Government (2014), Technical Flood Risk Management Guideline: Flood Hazard, Australian Emergency Management Handbook Series.
- Australian Institute of Disaster Resilience (2017), Flood Information to Support Land-use Planning, Australian Disaster Resilience Handbook Series.
- Australian Emergency Management Institute *(Editor)* (2013), *Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia*. Edited and published by the Australian Emergency Management Institute, part of the Australian Government Attorney-General's Department
- BMT WBM (2009). *Tweed Valley Flood Study - 2009 Update*. Prepared for Tweed Shire Council
- BMT WBM (2010). *Tweed Valley Flood Study, Additional Climate Change Scenario*. Letter report prepared for Tweed Shire Council
- BMT WBM (2014). *Tweed Valley Floodplain Risk Management Study*. Prepared for Tweed Shire Council.
- BMT WBM (2016). TUFLOW User Manual. Version 2016-12-AE.
- BMT WBM (2014). *Tweed Valley Floodplain Risk Management Plan*. Prepared for Tweed Shire Council.
- CIRIA (2013). *The International Levee Handbook*. Published by CIRIA, Griffin Court, 15 Long Lane, London EC1A 9PN, UK.
- Engineers Australia (1987). *Australian Rainfall and Runoff - A Guide to Flood Estimation*. Edited by D. Pilgrim.
- Haynes, K., Coates, L., Dimer de Oliveira, F., Gissing, A., Bird, D., van den Honert, R., Radford, D., D'Arcy, R, Smith, C. (2016). *An analysis of human fatalities from floods in Australia 1900-2015*. Report for the Bushfire and Natural Hazards CRC.
- 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.