Appendix G

Memorandum

SUBJECT: North Byron FRMS&P – Calibration Update for March 2017

1. INTRODUCTION

On the 31 March 2017, ex-Tropical Cyclone Debbie crossed into the Northern Rivers region in New South Wales providing heavy rainfall across the Brunswick River Basin. It resulted in flooding from Brunswick River, Marshalls Creek and Simpsons Creeks and inundation in several localities such as Mullumbimby, Ocean Shores, Billinudgel, and Brunswick Heads.

Following this event BMT were commissioned to collate and review all available rainfall and flooding data on behalf of Byron Shire Council. This analysis was presented in the *Byron Shire Flood Review Ex -Tropical Cyclone Debbie* (Reference 1).

WMAwater has since been commissioned to undertake the North Byron Floodplain Risk Management Study and Plan (FRMSP). The initial stages of the FRMSP are outlined below.

WMAwater initially undertook a peer review of the hydrologic and hydraulic models developed by BMT with a final review submitted to the FMC on 9th July 2018 with an outline of the review presented in Section 2.1. A list of recommendations were made and subsequent revisions to the TUFLOW model were undertaken and the modelling package calibrated to the March 2017 event. A draft calibration report was submitted to the FMC on 13th September 2018.

Following the FMC, a review to confirm that the results of the Flood Frequency Analysis (FFA) at the Durrumbul gauge could be replicated by the updated model was undertaken. The TUFLOW model could not initially replicate the design flows from the FFA across the entire suite of design events. This process highlighted additional areas for review of the XP-RAFTS hydrologic model and revisions that would need to be addressed. These are detailed in Section 2.2.

Revisions to the XP-RAFTS model were undertaken and the updated modelling package was calibrated to the March 2017 event and verified against the January 2012 event based on recorded rain gauge and stream gauge data. The calibration process and subsequent results are outlined in Section 4 to Section 7.

2. REVIEW PROCESS

There have been two peer reviews of the BMT modelling package undertaken by WMAwater:

- Initial Review - part of the FRMSP process
- Secondary Review – model updates recommended from the initial review highlighted additional issues with the modelling package.

2.1. Initial Peer Review BMT Modelling Package

The initial review of the hydrologic and hydraulic models developed by BMT in the *North Byron Shire Flood Stud*y (Reference 2) was reported to the FMC on 9th July 2018, establishing that :

- The hydrologic model which has been developed using XP-RAFTS was fit-for-purpose and appropriately set up;
- The hydraulic model, developed using TUFLOW (version 2013-12AE-w64), was running and working well and meets standard quality criteria;
- Notwithstanding this, it was recommended the following updates were undertaken:
    - Incorporate latest topographic features and detail of missing structures into the hydraulic model configuration;
    - Incorporate the March 2017 event into model calibration and verification;
    - Further sensitivity tests of the form losses upstream of Mullumbimby;
    - Sensitivity tests on the initial losses for forested areas in design events, and
    - Sensitivity tests on the manning's n values adopted in the hydrologic model.

The recommended updates and sensitivity tests have been undertaken and submitted to Council and the FMC.

<u>Updated TUFLOW Model</u>

The TUFLOW model was updated to include the following:

- Hydraulic Structures
    - Tuckeroo Avenue Culverts (Mullumbimby),
    - Drain/Bund south of Mullumbimby,
    - Orana Road Culvert (Ocean Shores),
    - Balemo Drive South Culvert (Ocean Shores),
    - Terrara Court Culvert (Ocean Shores),
    - Golf Course Bridge (Ocean Shores).
    - Bonanza Drive Culvert (Billinudgel),
    - Wilfred Street Culvert (Billinudgel),
    - Pacific Motorway Culvert (Billinudgel),
    - Balemo Drive North Culvert (Billinudgel/Ocean Shores).
- Development
    - Tallow Wood Estate Stage 4 (Mullumbimby),
    - Waterlily Park survey (Ocean Shores),
    - Shara Boulevard Sports Field (Billinudgel).
- Model Extension
    - Model Extended 2.1km upstream of the Durrumbul gauge
    - Model extended upstream of Kallaroo Circuit culvert
- Bathymetry
    - Brunswick River and Marshalls Creek – NSW OEH
- Additional Model Domain
    - Added additional model domain for the Ocean Shores area.

2.2. Additional Modelling Review

Following the extension of the model upstream of the Durrumbul gauge, significant topographic changes and the addition of new hydraulic structures to the model, it was necessary to confirm that the results of the Flood Frequency Analysis (FFA) at the Durrumbul gauge could be replicated by the updated model.

The TUFLOW model could not initially replicate the design flows from the FFA across the entire suite of design events. This process highlighted additional areas for with the XP-RAFTS hydrologic model that would need to be addressed:

- The Williams Bridge storage basin overestimated the storage and restriction of flow in the area and was not representative of the catchment;
- The slope or gradient parameter for each individual subcatchment was too steep in the upper parts of the Brunswick River catchment and not representative of catchment conditions. This led to a significant overestimation of peak flow in this area and affected calibration to the March 2017 event and the FFA results;
- The manning's 'n' roughness coefficient parameter was underestimated in heavily vegetated areas and the spatial application of the roughness coefficient was questionable;
- The variable application of initial loss and continuing loss values across the catchment based on land uses was not considered to be best practice or appropriately justified;
- The storage coefficient multiplication factor (Bx) of 1.5 initially used to modify the storage time delay in all sub-catchments except Marshalls Creek and Yelgun Creek was not appropriately justified.

Details of changes required to the hydrologic model and reasoning are listed below:

- The basin at Williams Bridge was removed from the hydrologic model;
- All catchment slope values were revisited using the equal area method, which is found to approximately match the average slope recommended by XP-RAFTS;
- The manning's 'n' roughness coefficient for each subcatchment was revised using a weighted average of the different land uses in each subcatchment and manning's 'n' values applied in line with experience and industry guidance;
- Consistent initial and continuing loss values were applied across the entire catchment, and
- The storage coefficient multiplication factor (Bx) of 1.5 was removed with no additional storage applied across the model. This is because the addition of an extra parameter did not add any improved representation of the catchment response.

3. AVAILABLE DATA

The stream gauge data, pluviometer rain gauge data and flood mark survey collected by BMT in Reference 1 were used in the calibration of the models to the March 2017 event. No further verification of the data was undertaken.

WMAwater collected additional daily read rainfall gauge data to assist in the calibration process.

3.1. Rainfall Gauge Data

Historical rainfall data for the March 2017 event was analysed, with the stations used for the calibration shown in Figure G1. Recorded rainfall depth for each gauge is shown in Table 1.

Table 1 - Historical Rainfall Data

Gauge Number	Gauge Type	Gauge Name	Rainfall Depth (mm) – 48 hrs
58019	Daily	Doon (McCabes Rd)	530
58129	Daily	Kunghur (The Junction)	575
58167	Daily	Uki (Tweed River)	602
58186	Daily	Murwillumbah (Tweed River)	460
58007	Daily	Byron Bay (Jacaranda Drive)	258
58040	Daily	Mullumbimby (Fairview Farm)	433
58070	Daily	Repentance Ck	357
58165	Daily	Upper Coopers Ck	384
58162	Daily	Nashua (Wilsons River)	234
58137	Daily	Kingscliff (Marine Parade)	209
558096	Pluviometer	Yelgun	354
558053	Pluviometer	Main Arm	494
558008	Pluviometer	Mullumbimby Ck (Mullumbimby Ck)	402
558005	Pluviometer	Lacks Ck (Middle Pocket)	433
558025	Pluviometer	Mullumbimby (Chincogan Repeater)	407
558034	Pluviometer	Mullumbimby (Upper Main Arm)	518

The variation in rainfall intensity across the storm (temporal pattern) derived from the pluviometer gauges are displayed in Figure G2. The data indicates two intense periods of rainfall during the event with a lull in between.

The totals at each available rain gauge from 9am 29th March to 9am 31st March were used to create a representation of the variation in rainfall over the catchment. This was done using the natural neighbour interpolation technique whereby the recorded rainfall depth at each gauge is used to create a rainfall depth grid over the entire catchment. This rainfall grid was then used to determine the rainfall depths for each individual sub-catchment in the hydrological model (refer Figure G3). Figure G3 displays a rainfall gradient in a south east direction from 518 mm at Upper Main Arm to 258m mm at Byron Bay. The temporal patterns from each pluviometer were applied to individual sub-catchments based on the closest pluviometer gauge to each sub-catchment.

3.2. Stream Gauge Data

Water level data was analysed for gauges shown in Table 2. The gauges and their locations are shown in Figure G4. The stage hydrographs recorded at each gauge for the March 2017 event are shown in Figure G5.

Table 2 - Historical Stream Gauge Data

Gauge Number	Gauge Name	Peak Stage Height (m)	Data Source
202001	Sherrys Bridge - Durrumbul	5.0	NSW Water
202402	Federation Bridge	4.2	MHL
202400	Billinudgel	4.5	MHL
202475	Orana Bridge	2.1	MHL
202403	Brunswick Heads	1.2	MHL

4. CALIBRATION – MARCH 2017

The key parameters considered in the calibration of the March 2017 event were:

- Initial loss
- Continuing loss

- Temporal patterns from pluviometer gauges

The calibration focused predominantly on the initial and continuing loss values. A range of initial loss values of between 50mm - 100mm and continuing loss values of between 1.5 – 2.5 mm/h were analysed, with the results documented in this memo based on the following adopted values:

Initial loss = 80 mm, Continuing loss = 2 mm/h

4.1. Durrumbul Gauge

Figure G6 shows the modelled and recorded level for the March 2017 event at Durrumbul gauge (202001). There is a good fit to the timing and shape of the recorded hydrograph except the TUFLOW model underestimates the falling limb of the flood event. Modelling produces a good match to the recorded peak flood level with results shown in Table 3.

Table 3 – Durrumbul – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
18.07	18.00	-0.07

Figure G7 shows the modelled and estimated flow for the March 2017 event at Durrumbul gauge (202001). There is a good match to the timing and shape of the estimated hydrograph except the TUFLOW model overestimates the initial flood peak and underestimates the falling limb of the flood event. When taking into account limitations in the rainfall data this can be considered as good fit.

Modelling produces a good match to the recorded peak flow with a difference of 2%, the results are shown in Table 4.

Table 4 – Durrumbul – Recorded and Modelled Peak Flood Flow

Recorded Flow (m^3/s)	Modelled Flow (m^3/s)	Difference (m^3/s)	% Difference
420	410	10	2%

4.2. Mullumbimby Federation Bridge

For the Federation Bridge (202402), water level data recorded after 5am the 31/03/2017 are missing as shown in Figure G8. Thus, the peak water level is missing and a level of uncertainty surrounds the remaining data, which should be used with caution. Modelled peak flow is 4.6m AHD while the highest recorded level is 4.2m mAHD as shown in Table 5. The overall shape of the hydrograph is reproduced.

Figure G8 shows the modelled peak level appears to be capped at 4.6mAHD and this is due to the bridge soffit being modelled at 4.6mAHD. The gauge is on the downstream side of Federation Bridge and until the bridge is overtopped the flood level will be capped at this level. While the gauge 202402 failed, a screen shot from a Mullumbimby resident shows the river level at Federation Bridge for gauge 558006. This gauge is used for real-time operational purposes and at the time of capture had not undergone quality assurance processes. However, the graph supports the results from the calibration and shows that while the model may be slightly overestimating the level at Federation Bridge it is reasonably representative of both the peak and the flood recession.

The area in Mullumbimby around Federation Bridge is a complex area with both rainfall and tidal influences. Flood behaviour in Mullumbimby is influenced by a number of hydraulic controls with joining tributaries upstream of Federation Bridge and locations of flow breakout. The gauge is located at a major hydraulic structure and any blockages may impact level recordings at this location.

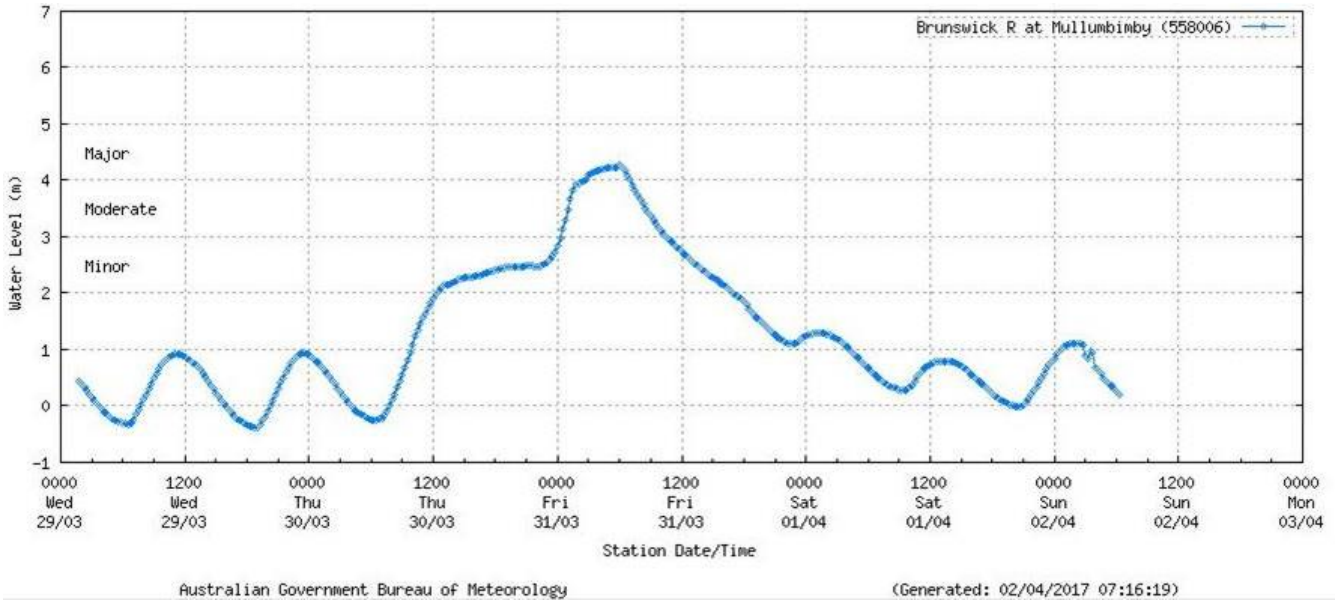

Diagram 1: Brunswick River at Mullumbimby (558006) river level captured on 02/04/2017.

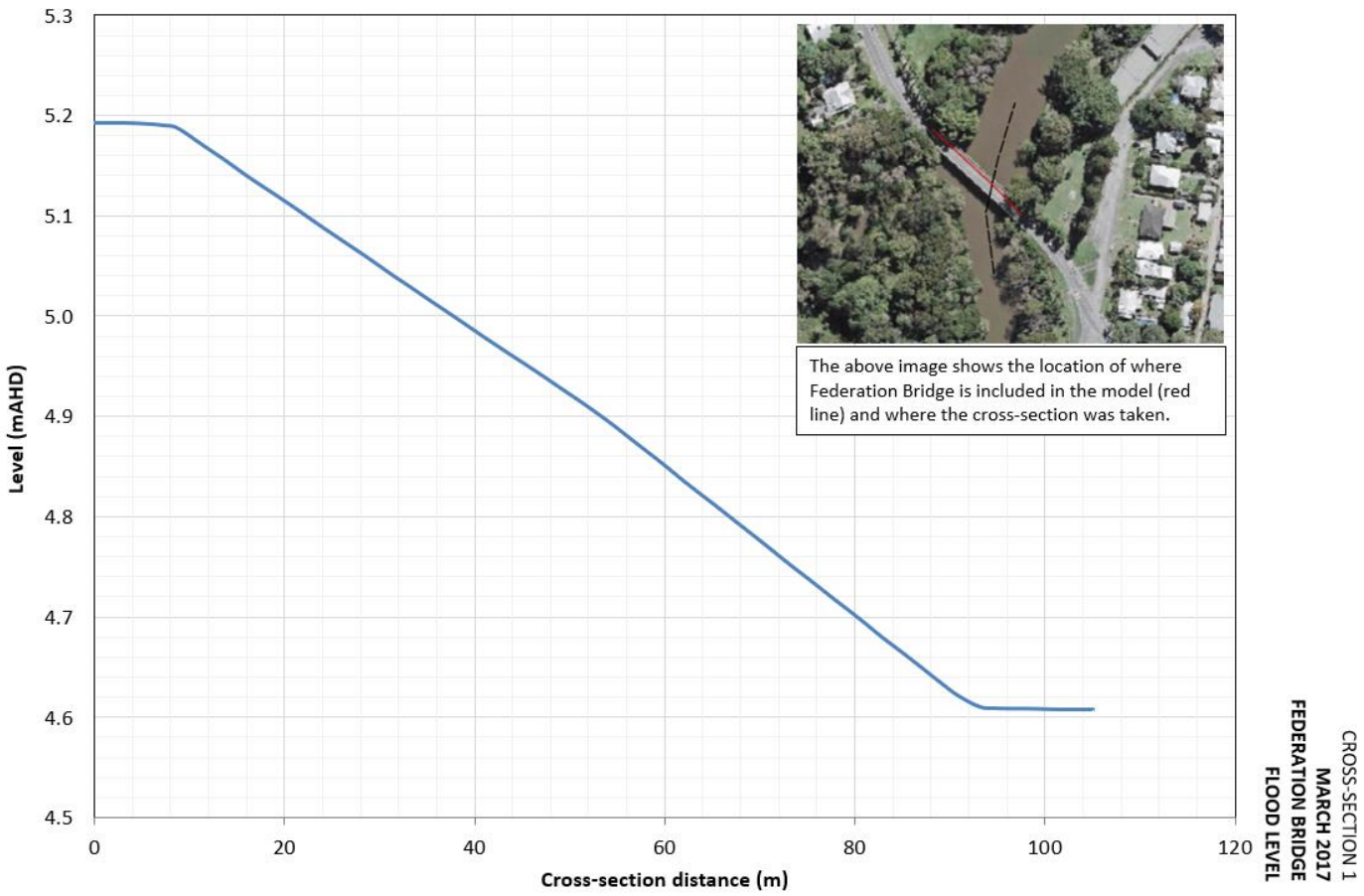

Table 5 – Federation Bridge – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
4.2 (gauge failed)	4.6	0.4

4.3. Billinudgel Railway Bridge

The comparison of modelled and recorded levels at Billinudgel Railway Bridge (202400) is shown on Figure G9. A reasonable match to recorded flood levels is achieved at the Billinudgel gauge with levels shown in Table 6. The initial peak is overestimated but overall a good fit to the recorded hydrograph shape is achieved.

Table 6 – Billinudgel – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
4.47	4.30	-0.17

4.4. Ocean Shores Orana Bridge

Results at Orana Bridge (Ocean Shores/New Brighton - 202475) are presented in Figure G10. There is a good match to the timing and shape of the recorded stage hydrograph with the peak reproduced within 0.1 m as shown in Table 7.

Table 7 – Orana Bridge – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
2.05	2.16	0.11

4.5. Brunswick Heads

Brunswick Head level gauge (202403) is located at the Brunswick River Mouth after the confluence of Brunswick River, Marshalls Creek and Simpsons Creek. This level gauge has been chosen as the downstream boundary condition of the TUFLOW model for the March 2017 event. The results at this gauges area presented in Table 8 and Figure G11. There is a good fit to the peak, shape and timing of the hydrograph.

Table 8 – Brunswick Heads – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
1.168	1.185	0.017

5. FLOOD MARKS – MARCH 2017

Two sets of flood mark survey for the March 2017 event were supplied by Byron Shire Council. These were combined in a database (Appendix G-1) which also included peak flood levels measured by the gauges discussed above, comprising:

- *Commissioned Survey*: 51 flood marks have been collected and surveyed by Council based on emails supplied by the public. Each flood mark is associated with a photograph taken during the flood or at the time of the survey.
- *Bill Paterson Survey*: An additional survey of 35 flood marks. This set does not contain any photographs or detailed description of the flood mark location. Each flood mark has been referenced within the database using a unique ID commencing with B.
- *Stream Level Gauges:* Five stream level gauges are operating in the model extent, two on Brunswick River (Durrumbul and Federation Bridge), two on Marshalls Creek (Billinudgel Railway Bridge and Orana Bridge) and one at Brunswick River Mouth. The measured level at Federation Bridge has been even included though the water level recorder failed during the flood event.

There are some surveyed flood levels in the data set which are considered inconsistent. These have been included in the below analysis for completeness, but they have been flagged as potentially inaccurate. A number of these points were also identified in the BMT *Byron Shire Flood Review Ex -Tropical Cyclone* (Reference 2), with the recommendation they are excluded from future analysis.

Inaccuracies are not uncommon for flood mark datasets. Errors with the data can occur as a result of:

- wrong recording of locations;
- errors in height measurements;
- recorded levels may not actually represent the peak level, they could be higher due to localised wave action or lower if a debris mark has subsided after the peak, and
- the recorded level may be as a result of local affects which are not reflected in the hydraulic model.

As such it is important to aim for general consistency across the catchment when comparing modelled results with surveyed flood marks and to not place too much emphasis on matching individual flood marks. This is particularly true for catchment scale models such as the North Byron model, which aims to represent general flood behaviour resulting from rivers and creeks. Peak modelled flood depth mapping, surveyed flood levels and modelled flood levels are displayed on Figure G22 to Figure G26.

5.1. Main Arm

There are 16 flood marks located in the Main Arm area (Durrumbul level gauge and 15 flood marks from the Bill Paterson Survey). This includes five flood marks from the Bill Paterson data that have been flagged as inconsistent - four due to a significant difference with adjacent flood marks of the stream gauge, and one flood mark is not from the March 2017 event.

The flood marks and the corresponding modelled peak flood levels are outlined in Table 9, with those flagged shown in Table 11. When taking into the account the questionable surveyed points, margin of error and the 12.5 m grid utilised in the TUFLOW model the calibration in Main Arm for the March 2017 is considered satisfactory.

Table 9 – Main Arm Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
L5	18.07	18	**-0.07**	
B13	19.39	19.05	**-0.34**	
B22	16.84	16.81	**-0.03**	
B26	20.85	20.71	**-0.14**	
B27	19.9	Outside Extent	Outside Extent	
B28	19.94	20.01	**0.07**	
B29	19.69	19.54	**-0.15**	
B3	19.63	19.3	**-0.33**	
B4	18.99	18.77	**-0.22**	
B5	19.07	18.86	**-0.21**	
B6	19.31	18.87	**-0.44**	

Table 10 – Main Arm – Flagged flood marks

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
B2	18.49	19.29	**0.8**	Flagged - inconsistent with adjacent marks
B23	16.45			Flagged - not the 2017 Flood Event
B24	19.19	18.09	**-1.1**	Flagged - stream gauge more accurate
B25	19.42	No Data	No Data	Flagged - stream gauge more accurate
B7	18.53	16.62	**-1.91**	Flagged - inconsistent with adjacent marks

5.2. Mullumbimby

There are 35 flood marks located in the Mullumbimby area including five flagged as inaccurate, namely:

- Federation Bridge water level recorder;
- Three of the 14 surveyed flood marks have been flagged. One is referring to a photo taken several hours after the peak flood, one indicates an incorrect spatial location and one is inconsistent with flood marks, and
- Two of the 20 flood marks from Bill Paterson survey have been flagged due to inconsistency with adjacent points.

The flood marks and the corresponding modelled peak flood levels are outlined in Table 11 with those flagged shown in Table 13.

The majority of flood marks are modelled within +/- 0.2 m which is considered a good match. Flood marks B12 is underestimated by 0.3 m and B10 is underestimated by 0.5 m which infers that the survey point could have been influenced by local circumstances not represented in the mode, or be questionable

There are several different hydraulic controls in and around Mullumbimby with tributaries joining and flow breakout or bypassing occurring. Any temporary change in flood dynamics like a partial blockage will impact on predicted flood behaviour. Given the complexity of this area Mullumbimby is considered satisfactorily calibrated.

There are eight flood marks outside the calibrated flood extent, with six of those marks in the urban area. There are multiple reasons why this may have occurred, including:

- Inundation caused by local runoff;
- Local blockage or debris that affected flood behavior, and
- The model not accurately representing the urban environment and terrain due to the catchment wide scale of the model.

Table 11 – Mullumbimby Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
50	4.25	Outside Extent	Outside Extent	
51	7.12	6.96	**-0.17**	
2	2.99	3.24	**0.25**	
3	6.7	Outside Extent	Outside Extent	

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
7	7.58	Outside Extent	Outside Extent	
39	4.13	4.25	**0.12**	
47	2.98	3.23	**0.25**	
40	4.14	4.34	**0.2**	
B1	8.52	Outside Extent	Outside Extent	
B8	6.29	6.26	**-0.03**	
B9	6.3	6.27	**-0.03**	
B11	7.2	7.11	**-0.09**	
B12	7.39	7.11	**-0.28**	
B14	7.29	7.11	**-0.19**	
B15	7.29	7.1	**-0.19**	
B16	7.29	7.1	**-0.19**	
B17	7.29	7.1	**-0.19**	
B18	7.3	7.09	**-0.21**	
B19	7.3	7.1	**-0.2**	
B20	5.46	5.21	**-0.25**	
B21	5.19	5.26	**0.07**	
B32	7.32	Outside Extent	Outside Extent	
B33	7.31	7.1	**-0.21**	
B34	6.29	Outside Extent	Outside Extent	
B35	5.08	5.22	**0.14**	

Table 12 – Mullumbimby – Flagged flood marks

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
L1	4.35	4.8	**0.45**	Failed gauge
13	4.91	5.17	**0.26**	Flagged in event review (BMT)
18	7.17	7.11	**-0.06**	Flagged in event review (BMT)
10	2.7	4.23	**1.53**	Photo after peak / flagged in event review (BMT)
B10	7.63	7.14	**-0.49**	flagged – inconsistent with adjacent point / flagged in event review (BMT)
48	7.28	3.23	**-4.05**	Wrong location
B10	7.63	7.14	**-0.49**	Flagged - inconsistent with adjacent point
B30	7.67	7.37	**-0.30**	Flagged - inconsistent with adjacent point
B31	7.13	7.40	**0.27**	Flagged - inconsistent with adjacent point
14	2.7	-Outside Extent	Outside Extent	Flagged in event review (BMT)

5.3. Brunswick Heads

There are seven flood marks located in Brunswick Heads including the Brunswick River level gauge. Four flood marks are located in the Brunswick Heads urban area. The flood marks and the corresponding modelled peak flood levels are outlined in Table 13, with those flagged as inaccurate shown in Table 15.

There is a good match at the gauge to the peak but the levels in the town are overestimated by 0.25 m – 0.4 m. There is no pit or pipe data included in the model for the Brunswick urban area which could account for flood water not dispersing into the river. A good fit to recorded flood levels is achieved in the Brunswick River.

Table 13 – Brunswick Heads Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
L4	1.168	1.18	**0.01**	

Table 14 – Brunswick Heads – Flagged flood marks

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
1	1.67	2.15	**0.48**	Flagged in event review (BMT)
9	1.96	2.02	**0.06**	Flagged in event review (BMT)
15	1.68	2.09	**0.41**	Flagged in event review (BMT)
41	1.84	2.12	**0.28**	Flagged in event review (BMT)
46	1.97	2.22	**0.25**	Flagged in event review (BMT)
11	3.97	2.26	**-1.71**	Flagged – inconsistent with adjacent point / flagged in event review (BMT)

5.4. Billinudgel

There are three flood marks in the Billinudgel area. The flood marks and the corresponding modelled peak flood levels are outlined in Table **15**, with those flagged shown in Table **16**.

There is a reasonable match at the Billinudgel gauge and point 42. Point 45 is underestimated by 0.63 m but this level does not fit in with the flood gradient between Billinudgel and Orana Bridge. The Billinudgel calibration provides a good fit with recorded levels.

Table 15 – Billinudgel Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
L2	4.47	4.32	**-0.15**	
42	4.62	4.43	**-0.19**	

Table 16 – Billinudgel – Flagged flood marks

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
45	3.73	3.1	**-0.63**	Model Boundary / flagged in event review (BMT)

5.5. South Golden Beach

South Golden Beach is bisected by the Capricornia Canal. Both sides of the area are protected by a levee on the bank of the canal. Non-returns flood gates drain South Golden Beach stormwater through the levee. Flood gates are closed when the canal water level is high and a flood pumping station then operates.

The levees crest level is set to 3.2m/3.3m AHD. Evidence from commissioned survey and photos taken during the flood event suggest that the maximum flood level in the Capricornia Canal didn't exceed 3.0m AHD. No breaches nor failures of the levee system was reported during the March 2017 flood event. Thus, flooding in the South Golden Beach area are considered to have been a result of stormwater runoff and not by water overtopping the levee. The hydraulic model only represents river/creek flooding and has not been established to represent local runoff.

There were 18 flood marks surveyed in the South Golden Beach area. The flood marks and the corresponding modelled peak flood levels are outlined in Table 17, with those flagged shown in Table 18.

Most of them (11) are located on the protected side of the town and thus are not relevant for the present study. ID33 flood marks refers to the 2005 flood event and has been noted. There is a good fit to surveyed flood levels at points 44, 35 and 30. Modelled flood level points 29 and 28 are overestimated by 0.25 m.

Table 17 – South Golden Beach Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
44	2.88	2.8	**-0.08**	
6	2.99	Outside Extent	Outside Extent	
30	2.77	2.77	**0**	
29	2.53	2.77	**0.24**	
28	2.53	2.75	**0.22**	

Table 18 – South Golden Beach – Flagged Flood Marks

Map ID	Surveyed Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)	Comments
43	2.59	Outside Extent	Outside Extent	Flagged in event review (BMT)
4	2.63	Outside Extent	Outside Extent	Flagged in event review (BMT)
19	2.33	Outside Extent	Outside Extent	Flagged in event review (BMT)
20	2.55	Outside Extent	Outside Extent	Flagged in event review (BMT)
32	3.39	Outside Extent	Outside Extent	Flagged in event review (BMT)
31	2.88	Outside Extent	Outside Extent	Flagged in event review (BMT)
34	2.29	Outside Extent	Outside Extent	Flagged in event review (BMT)
35	2.86	Outside Extent	Outside Extent	Flagged in event review (BMT)
36	2.74	Outside Extent	Outside Extent	Flagged in event review (BMT)
37	2.23	Outside Extent	Outside Extent	Flagged in event review (BMT)
22	2.88	Outside Extent	Outside Extent	Flagged in event review (BMT)
23	3.16	Outside Extent	Outside Extent	Flagged in event review (BMT)

Map ID	Surveyed Flood Level (m AHD)	Modelled Flood Level (m AHD)	Difference (m)	Comments
33	2.95			Not the 2017 Flood Event

5.6. Ocean Shores

There were six flood marks surveyed in the Ocean Shores area, four on Balemo Drive are outside of the modelled flood extent.

The flood marks and the corresponding modelled peak flood levels are outlined in Table **19**, with those flagged as inaccurate shown in Table **20**.
Overland flow from the urban area of Ocean Shores has not been independently modelled which would account for the flood marks being outside the model extent. Point 21 is overestimated by 0.1 m.

Table 19 – South Golden Beach Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
12	2.58	Outside Extent	Outside Extent	
16	1.79	Outside Extent	Outside Extent	
17	2.7	Outside Extent	Outside Extent	

Table 20 – South Golden Beach - Flagged flood marks

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
5	2.7	Outside Extent	Outside Extent	Flagged in event review (BMT)
8	2.64	Outside Extent	Outside Extent	Flagged in event review (BMT)
21	2.76	2.64	**-0.12**	Flagged in event review (BMT)

5.7. New Brighton

There were five flood marks surveyed in New Brighton. The maximum recorded level at Orana Bridge level gauge is also considered. The flood marks and the corresponding modelled peak flood levels are outlined in Table **21**, with those flagged shown in Table 22.

The peak flood level at the Orana Bridge gauge was overestimated by 0.1 m, with a good match at points 38, 24 and 26. Points 25 and 27 are overestimated by approximately 0.2 m.

Table 21 – New Brighton Surveyed Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
L3	2.05	2.12	**0.07**	
38	2.39	2.52	**0.13**	
27	2.50	2.73	**0.23**	
25	2.39	2.60	**0.21**	

Table 22 – New Brighton - Flagged Flood Levels

Map ID	Surveyed Flood Level (m AHD)	Modelled flood Level (m AHD)	Difference (m)	Comments
24	2.41	2.50	**0.09**	BMT Flagged
26	2.47	2.50	**0.03**	BMT Flagged

6. VERIFICATION – JANUARY 2012

The model structure was considered appropriate for both January 2012 and March 2017, therefore the initial loss was adjusted to represent storm conditions. A range of initial losses between 10 mm and 100 mm were analysed, the results documented in this memo based on the following adopted values:

Initial loss = 10 mm, Continuing Loss = 2 mm/h

6.1. Durrumbul Gauge

Figure G12 shows the modelled and recorded peak for the January 2012 event at the Durrumbul gauge (202001). There is a reasonable match to timing and shape of the recorded hydrograph except the model is early on the rising limb and underestimates the falling limb. Modelling produces a good match to the recorded peak with results shown in Table 23.

Table 23: Durrumbul – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
17.53	17.50	-0.03

Figure G13 shows the modelled and recorded flow for the January 2012 event at the Durrumbul gauge (202001). Modelling produces a good match to the recorded peak with a difference of 3%, with the results shown in Table 24.

There is a good fit to the timing and shape of the hydrograph except that model is early on the rising limb and overestimates the initial peak. Even with these two issues the calibration is an improvement on the previous models calibration which underestimated flow by approximately 100 m^3/s as shown in Figure G14.

Table 24: Durrumbul – Recorded and Modelled Peak Flood Flow

Recorded Flow (m^3/s)	Modelled Flow (m^3/s)	Difference (m^3/s)	% Difference
264	273	9	3%

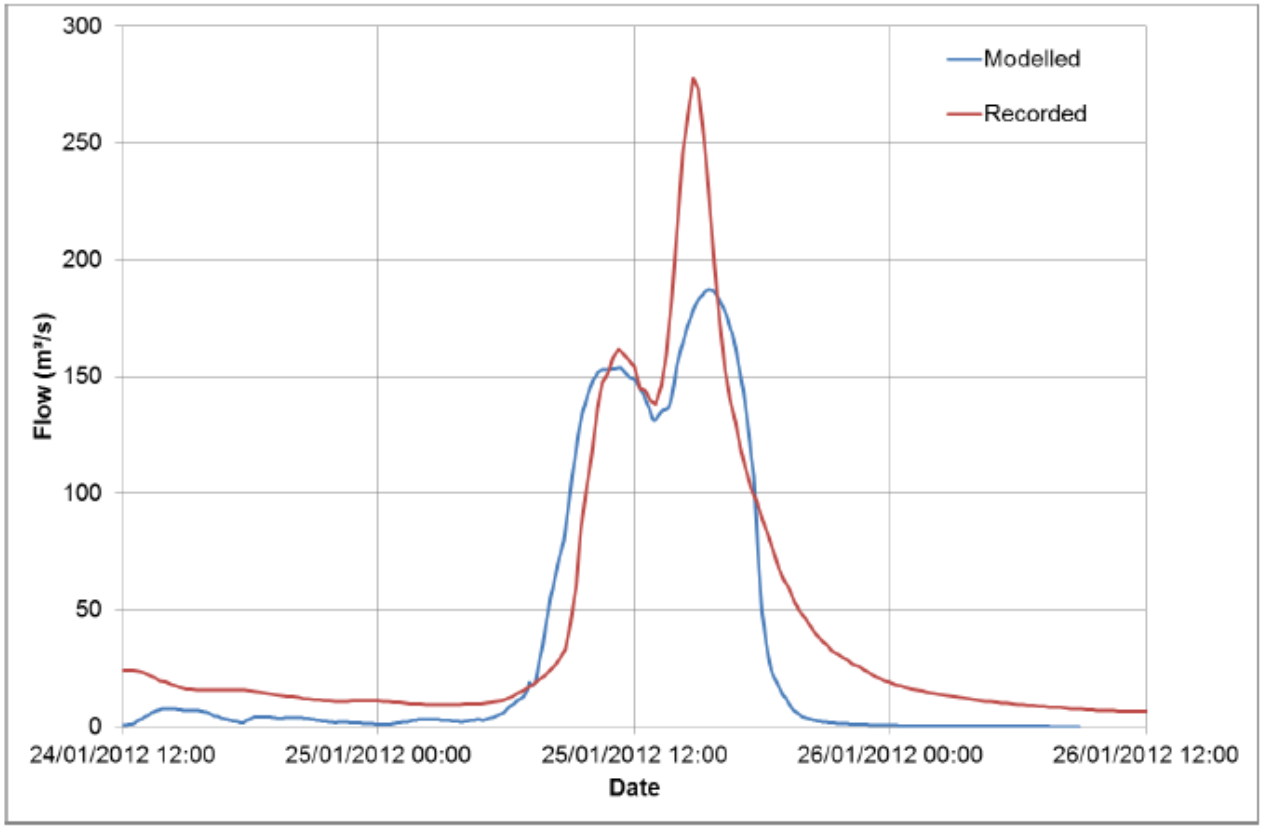

Figure G14: Graph - BMT North Byron Flood Study Report Comparing XP-RAFTS Discharge to Recorded Flow at Durrumbul – 2012 (Reference 1)

6.2. Mullumbimby Federation Bridge

A comparison of the modelled and recorded levels at Federation Bridge (202402) is shown in Figure G15. A reasonable match to the recorded hydrograph is achieved. The peak is overestimated by 0.44 m as shown in Table 25 and the timing of the rising limb is early.

When comparing the results to the calibration in the previous flood study (Reference 1) shown in Figure G16, the updated modelling package is able to reproduce the results with similar accuracy.

There is a slight trend in the model to slightly overestimate flood levels at Federation Bridge, as seen in both the March 2017 and January 2012 flood event. These overestimations are primarily localised and this is likely due to the complexities in this area, such as the impact any blockages at the bridge may cause to the recorded level.

Table 25: Federation Bridge – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
3.89	4.33	0.44

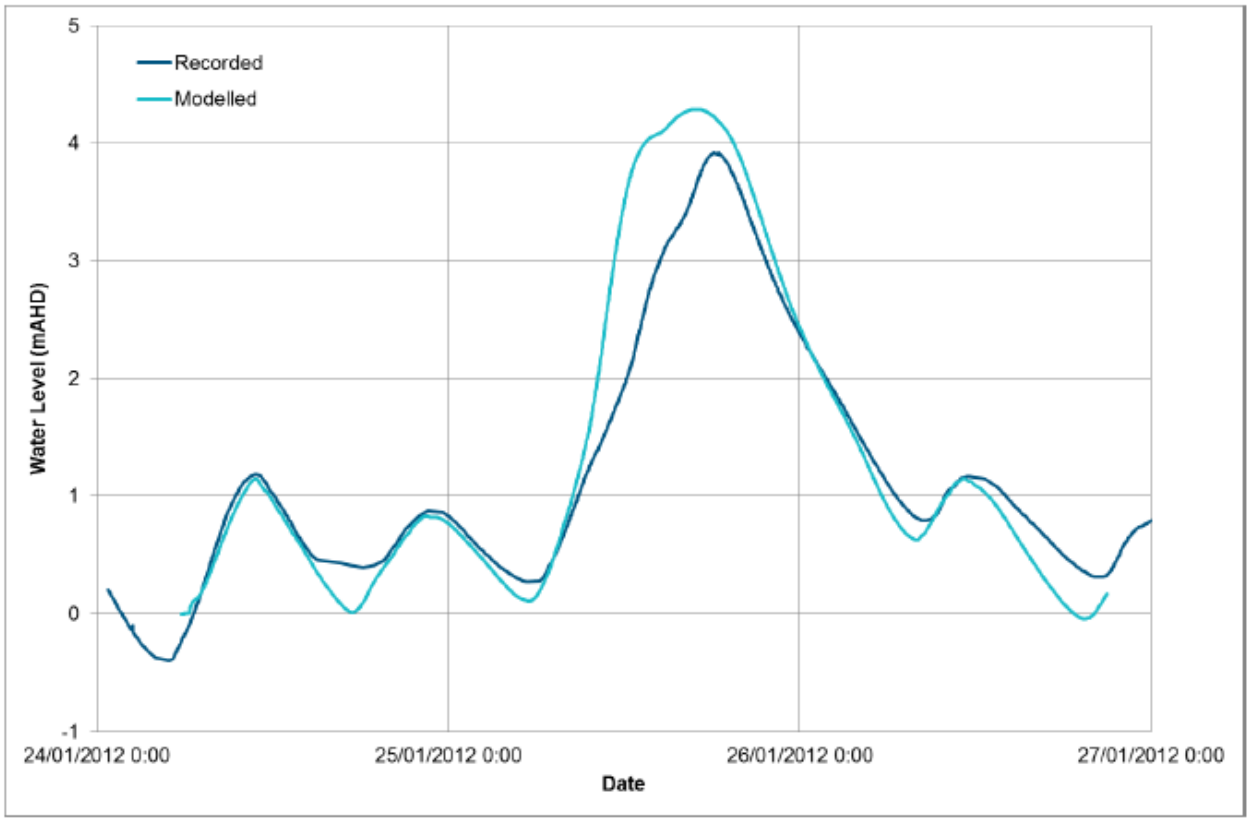

Figure G16: Graph - BMT North Byron Flood Study Report Comparing Modelled Level at Federation Bridge to the Recorded Level (Reference 1)

6.3. Billinudgel Railway Bridge

A comparison of the modelled and recorded levels of the BOM gauge and MHL gauge are shown in Figure G17. The MHL and BOM gauge are located at approximately the same location but there is a discrepancy between the recorded peak flood levels of approximately 0.25 m. A thorough investigation and analysis was undertaken to try and determine the reason for the difference, with both agencies contacted, but a resolution was not forthcoming.

It appears that in the previous flood study (Reference 1) that the BOM recorded hydrograph was used as shown in Figure G18. There is no explanation in the report as to why this gauge was chosen. As it could not be confirmed which gauge is correct the BOM gauge was selected as that is what was used in the Flood Study with the MHL gauge displayed for transparency.
A good fit to the recorded peak level was achieved with a difference of 0.13 m as shown in Table 26. A better fit to the falling limb was achieved in comparison the previous study (Reference 1).

Table 26: Marshalls Creek at Billinudgel – Recorded and Modelled Peak Flood Level

BOM Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
3.35	3.48	0.13

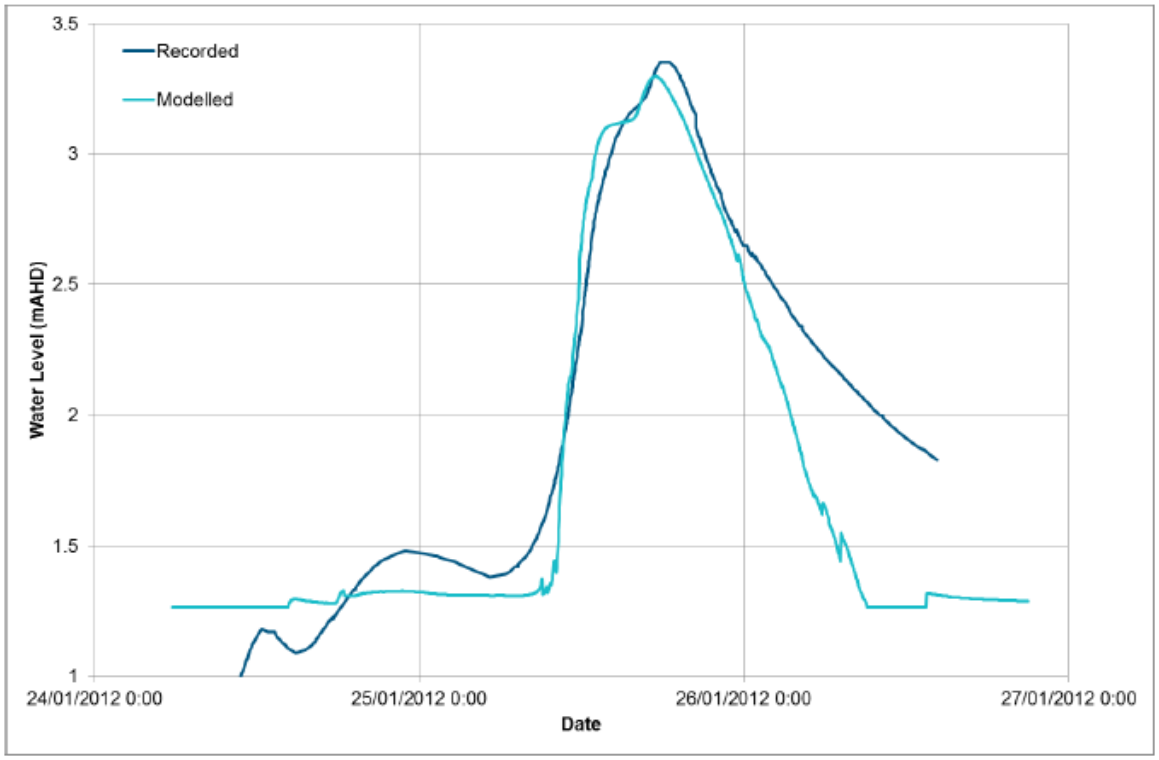

Figure G18: Graph - BMT North Byron Flood Study Report comparing Modelled Level at Marshalls Creek at Billinudgel to Recorded Level (Reference 1)

6.4. Ocean Shores Orana Bridge

The comparison of modelled and recorded levels at the Orana Bridge gauge (202475) is shown in Figure G19. A good match to the peak is achieved with results shown in Table 27. A reasonable match to timing and shape of the recorded hydrograph is achieved except that the failing limb tends to be underestimated.

In comparison to the previous flood study calibration shown in Figure G20 the updated modelling package produces a better match to the peak and replicates the shape and timing with similar accuracy.

Table 27: Marshalls Creek at Orana Bridge – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
1.39	1.43	0.04

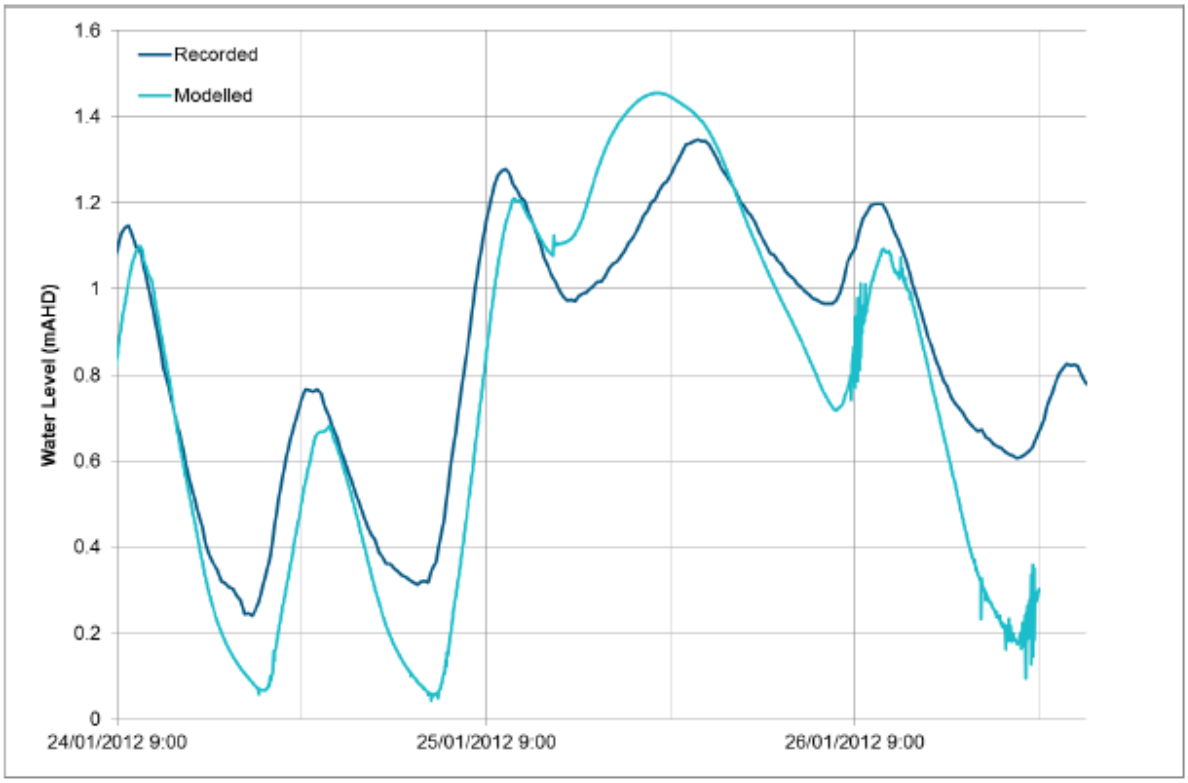

Figure G20: Graph - BMT North Byron Flood Study Report Comparing the Modelled level at Orana Bridge to the Recorded Level - 2012 (Reference 1)

6.5. Brunswick Heads

The comparison of recorded and modelled levels at the Brunswick Heads (202403) gauge is shown in Figure G21. A good match to the recorded peak is achieved with a difference of 0.08 m as shown in Table 28.

Table 28: Brunswick Heads – Recorded and Modelled Peak Flood Level

Recorded Level (mAHD)	Modelled Level (mAHD)	Difference (m)
1.06	0.98	0.08

7. CONCLUSION

Overall, the calibration achieved a good fit of the March 2017 event, with the following points of note.

- A good fit to the Durrumbul gauge was achieved for both the recorded level and flow.
- A satisfactory fit to the Main Arm surveyed flood levels was achieved when the questionable flood marks and 12.5 m grid in the TUFLOW model are taken into account.
- The Federation Bridge gauge malfunctioned therefore the remaining data at the gauge is questionable. The majority of surveyed flood marks are within +/- 0.2 m with a trend towards underestimating the peak level. The results are still within the margin of error of flood mark survey and modelling and therefore considered satisfactory.
- A good fit to the peak flood level at the Billinudgel gauge and the two flood marks upstream was achieved.

- There is a trend of overestimation of peak flood levels in the South Golden Beach, New Brighton and Ocean Shores, but the differences are still within a reasonable margin of error.
- A good fit to the Brunswick gauge was achieved although the Brunswick urban area flood marks were overestimated. However the urban drainage and culverts are not represented in the TUFLOW model would mostly accounts for these differences.

Overall the verification of the January 2012 event achieved a good fit, with the following points of note.

- A good fit to the Durrumbul gauge was achieved for both the recorded level and flow, with a substantial improvement on the previous flood study calibration.
- A reasonable fit to the Federation Bridge gauge, with a similar result to the previous flood study.
- A reasonable fit to the BOM gauge at Billinudgel, with a similar result to the previous flood study. Uncertainty remains regarding the discrepancy in levels with the MHL and BOM gauges at the same location.
- A good fit to the Orana Bridge gauge with an improvement on the previous flood study.
- A good fit to the Brunswick Heads gauge was achieved.

The North Byron model is a catchment scale model, established to represent the flood behaviour across a large area, which includes a number of creeks, towns, and hydraulic control structures. As such, the model is considered to represent the March 2017 and January 2012 event satisfactorily and is considered fit for use for the North Byron Floodplain Risk Management Study and Plan.

List of Figures

References

1. North Byron Shire Flood Study (BMT WBM, 2016)
2. Tweed-Byron Coastal Creeks Flood Study (BMT WBM, 2010)
3. Byron Shire Flood Review for Ex-Tropical Cyclone Debbie (BMT WBM, 2017)