Peer Review of Balgal Beach Flood Study

Customer	Townsville City Council
Project	A10416
Deliverable	005
Version	00
	26 April 2022

Document Control

Document Identification

Title	Peer Review of Balgal Beach Flood Study
Project No	A10416
Deliverable No	005
Version No	00
Version Date	26 April 2022
Customer	Townsville City Council
Classification	BMT (OFFICIAL)

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Amendment Record

The Amendment Record below records the history and issue status of this document.

Version	Version Date	Distribution	Record
00	26 April 2022	Townsville City Council	Draft report

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1 Introduction

1.1 Background

Townsville City Council (TCC) is currently updating flood modelling and mapping within the LGA as part of the *Townsville Flood Modelling and Mapping Project* (the Project). BMT has been engaged to provide expert peer review for the Project to support achieving sound and defendable outcomes for TCC by:

- Ensuring the study follows latest industry standard techniques and best-practice;
- Instilling confidence in the study products and outputs;
- Identifying potential missed opportunities which might be rectified within this study, or flagged for future works.

The modelling and mapping for the *Townsville Flood Modelling and Mapping Project* has been commissioned under five separate contracts with each contract pertaining to a hydrological catchment (or group of catchments). These five contracts are as follows:

- Bohle River catchment
- Black River, Althaus and Bluewater Creeks
- Ross River and Surrounds
- Alligator Creek and Whites Creek.
- Magnetic Island and Balgal Beach (five separate studies):
  - Balgal Beach
  - Arcadia
  - Horseshoe Bay
  - Nelly Bay
  - Picnic Bay.

This peer review report documents the review findings for the **Balgal Beach Flood Study** prepared by AECOM under the under the Magnetic Island and Balgal Beach contract.

1.2 Supplied Data

BMT has relied on information from the following sources in the completion of this review:

- Balgal Beach Flood Study Base-line Flooding Assessment Volumes 1 and 2, Revision A dated 18 January 2022 (AECOM, 2022)
- Request for Quotation: Townsville Recalibrated Flood Modelling and Mapping – Magnetic Island & Balgal Beach (TCC, undated)
- Townsville Recalibrated Flood Modelling and Mapping Naming Convention Report (TCC, March 2020)
- Hydrologic Models:
  - BB_DES.xp

- BB_CAL_PMF_v2.xp
- Supporting GIS datasets

- Hydraulic Models:
  - TUFLOW model BB-~s1~-~s2~-~e1~-~s3~~e2~.tcf

1.3 Peer Review Process

The peer review covers the following aspects:

- Technical review of the models for general configuration, parameters, calibration performance, model health etc;
- Assessment of conformance or otherwise to the Australian Rainfall and Runoff 2019 guideline (ARR2019);
- Assessment of the degree to which the deliverables provided to Council meet the stated aims in the respective project briefs and associated consultant proposals; and
- Commentary on the ability of the study outputs to be used for end purposes (i.e. application of the new flood models, flood maps and flood hazard maps for the planning, new development and rezoning purpose).

We have utilised a traffic light system to indicate how significant an issue might be. Each issue is allocated a colour (green, yellow or red) in accordance with Table 1 1. Where a potential issue has been identified, we have provided our recommendations on how to address or further investigate the issue.

At the end of each key review section, a summary table is provided of key review observations and recommendations along with an indication of the significance of the issue.

Table 1.1 Significance of Issue

Category	Category Description
Green	Checks have showed either no issues or issues are of a minor or cosmetic nature that don’t have any bearing on model results
Yellow	An issue which is unlikely to be significant but does warrant further checking or justification.
Red	Potentially significant issue which may have implications on model results and further investigation is required

1.4 Limitations

In preparing this report, BMT has relied upon, and presumed accurate, information (or absence thereof) provided by AECOM. Except as otherwise stated in this report, BMT has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change. It is assumed that the results provided by AECOM correspond to the definitions in the control files provided for the model runs.

2 Modelling Overview

The Balgal Beach Flood Study uses a hydrologic XP-RAFTS model to convert rainfall to runoff. Runoff hydrographs are then extracted from the XP-RAFTS model and applied as inflows to a TUFLOW HPC hydraulic model. The TUFLOW HPC model also includes catchment area which is modelled with direct rainfall input. The direct rainfall is applied in combination with the XP-RAFTS derived inflows.

The TUFLOW model uses a 5m model grid and has been used to simulate design flood events with AEPs ranging from 50% (most frequent) to 0.05% (rarest). The Probable Maximum Flood (PMF) has also been assessed along with climate change scenarios for the 2% and 1% AEP events. The design hydrology is based on the Australian Rainfall and Runoff 2019 guideline (ARR2019) (Ball et al, 2019).

The XP-RAFTS and TUFLOW models have been calibrated to the historic events of January/February 2019 and April 2014.

The remainder of this report sets out the key findings from our peer review.

3 Hydrologic Assessment

3.1 Background

As described in Section 2, the hydrologic modelling was undertaken using XP-RAFTS software. The XP-RAFTS model is a new model developed for the Balgal Beach Flood Study.

The peer review of the hydrologic modelling is limited to its overall suitability and defensibility of its implementation. The hydrologic review covers following aspects:

- High level checks on the appropriateness of the hydrologic modelling for the purposes of the flood study.
- Consistency checks that the hydrographs output from XP-RAFTS are applied at appropriate locations in the TUFLOW model and that all runoff is accounted for in the TUFLOW model.
- The application/implementation of ARR2019 methodology in deriving appropriate design hydrology.

3.2 Hydrologic Review

General Comments

A check on the overall modelled catchment area showed a good match to the catchment area delineated in GIS (138km^2). The split subarea approach to separate out impervious area has not been used. Where applicable, impervious area has been specified as a percentage of the subarea. As such, an impervious rainfall loss has not been applied in the model. Given the small extent of urban area within the catchment and that the urban areas are included within the TUFLOW model extent (which includes impervious loss values), then this only represents a minor limitation to the XP-RAFTS model which does not follow through the flood study.

Of the modelled catchment area, 0.39km^2 (less than 0.5% of the total catchment) is attributed to impermeable land uses which appears appropriate based on aerial images.

The XP-RAFTS subarea ordering has been reviewed against topography and was found to be generally satisfactory. An issue was noted in the lower reaches of the catchment where subarea BB185 (conveying the total running flow hydrograph in Hencamp Creek) links to subarea BB169 (Rollingstone Creek) (see Figure 3.1). As these subareas are all located within the area to which direct rainfall is applied in TUFLOW then this issue within the hydrologic routing will not affect the TUFLOW results. Care should be exercised if using the hydrologic model for extracting flows in the lower reaches without the accompanying use of the TUFLOW model.

A simple stream lag has been used for stream routing through the catchment. This is generally only appropriate in small urban catchments. When applied in rural catchments it may result in an under attenuation of flow. This is not a concern for the catchment downstream of the Bruce Highway as direct rainfall replaces the hydrologic flows but it is a limitation to the upstream catchment total flows. It is noted that the model has been reasonably calibrated and so this reduces the uncertainty. It is recommended that the way in which lag times have been calculated is documented.

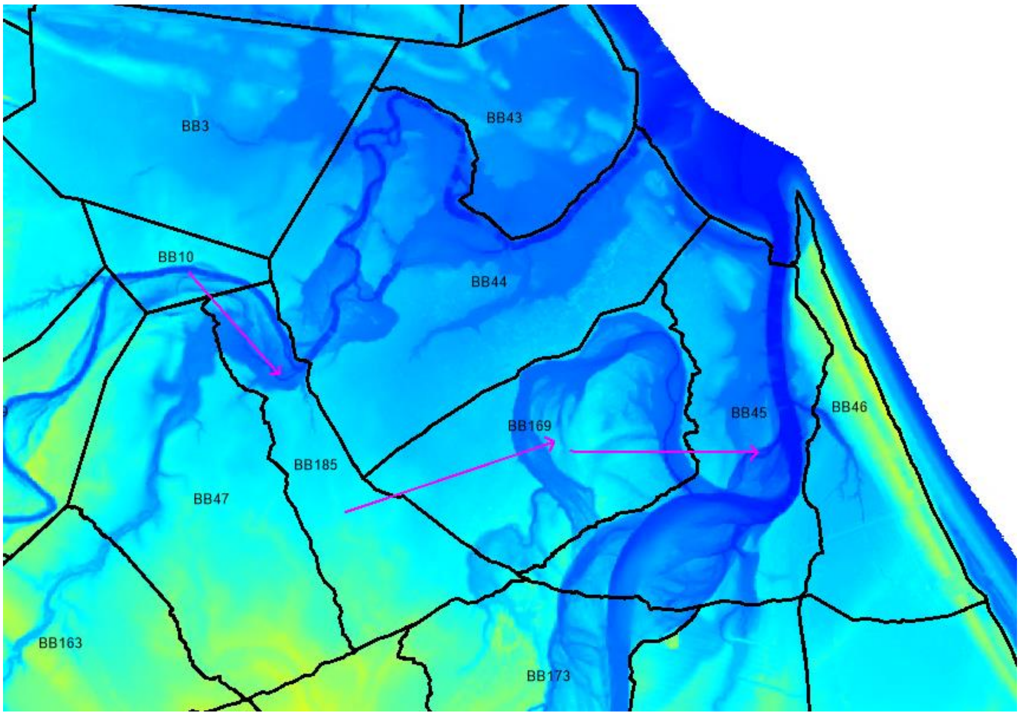


Figure 3.1 XP-RAFTS subareas with arrows showing cross over from Hencamp Creek to Rollingstone Creek

A check of the vectored slope in the main town (flat areas) has found that the slopes are generally reasonable. Some of the slopes in the upper parts of the catchment trigger warnings in XP-RAFTS as they are in excess of 30%. Given that the model has been appropriately calibrated then this is not a cause for concern. It is recommended however that the way in which these slopes have been derived is documented.

Model Calibration/Verification

The hydrologic model was simulated for the historic events which occurred in January/February 2019 and April 2014. There is one stream gauge within the catchment (Rollingstone Alert) which is located on Rollingstone Creek upstream of the Bruce Highway. Hydrologic calibration to recorded (rated) flows shows that a good match was achieved in terms of peak flow and timing to the 2014 event. The 2019 event was a multipeaked event and the model generally shows good agreement to the timing of recorded flood peaks. The largest of the flood peaks shows a reasonable match to peak flood magnitude between the modelled and recorded events. A number of the other smaller peaks are overstated in the model. AECOM note the limitations of available rainfall data within the catchment, particularly the lack of a rainfall gauge in the upper catchment.

In BMT’s opinion a reasonable calibration has been achieved for the purposes of the flood study which is focused on the magnitude and timing of the flood peak.

The AECOM report states a Bx calibration parameter of 0.8 was applied for the 2019 event (Section 2.2.1). This appears to be a typo as in the model a value of 1.8 is applied which is consistent with that used for the 2014 event and the design events. It is recommended that this is reviewed and amended in the report.

3.3 Summary of Hydrologic Model Observations and Recommendations

Table 3.1 Hydrologic Model Development and Calibration Summary

ID	BMT Observation	BMT Recommendation
3.1	Pervious rainfall losses have been applied across the entire model including impervious surfaces	As this will not affect the flood study results due to replacement with TUFLOW direct rainfall, no further recommendation made.
3.2	Model uses simple catchment lagging and not routing. This is only recommended for small urban catchments	As model calibration has been undertaken to historic events then this has reduced the uncertainty of this approach and a change to routing is not warranted. It is recommended that the approach used is documented.
3.3	Hencamp Creek appears to erroneously flow into Rollingstone Creek in the lower reaches of the catchment.	Will not change study outcomes as area is within hydraulically routed TUFLOW domain. Recommended that this is reviewed and fixed for completeness and future usability of the model.
3.4	Approach to extracting catchment slopes not documented.	The way in which slopes have been calculated should be documented in the report
3.5	Report refers to a Bx parameter value of 0.8 being applied for the 2019 event whereas the model shows this to be 1.8.	Amend in report.

4 Hydraulic Model Development and Calibration

4.1 Background

The hydraulic model is a new model developed using TUFLOW software. The TUFLOW model is predominantly 2D with nested 1D culvert elements. It uses TUFLOW HPC along with its Sub-Grid-Sampling (SGS) feature. The model was simulated using TUFLOW build 2020-10-AA-isp which was the latest version at the time of the assessment.

4.2 General Considerations

The supplied model files include a single TUFLOW control file (tcf) as follows:

BB-~s1~-~s2~-~e1~-~s3~~e2~.tcf

TUFLOW's events and scenarios feature has been used allowing the same tcf to be used to simulate different design events, calibration events and sensitivity tests.

Naming Conventions

TCC has nominated a standardised hydraulic model naming convention to be used on models developed for the Project. The naming adopted by AECOM broadly meets the naming convention although does not conform exactly. For example, the AEP identified is larger than the requested 3 characters. A model run identifier is also not included which is important for ongoing model quality control practices.

Whilst not strictly in accordance with the requested naming conventions, in BMT's opinion the adopted naming remains clear, logical and allows TCC to easily identify it is a Balgal Beach model (or result file). It is however recommended that a run ID is incorporated into the model.

General Setup

The model folder structure is set up in accordance with TCCs requirements and follows TUFLOW's recommended folder structure approach. Default model settings are generally applied as recommended. In a test simulation, BMT was able to initialise and run the design case model with the supplied model files.

The extent of the model is appropriate to cover the main urban areas within the Rollingstone and Hencamp Creek catchments. However, given the relatively small size of the model and the very quick simulation times, it would have been possible to include more of the upstream sub-catchments as local inflows into TUFLOW. This would have increased the extent of the hydraulic model upstream of the Bruce Highway, which at present is very close to the hydraulic model boundary

4.3 Hydraulic Model Development and Calibration

Topography

The base topography is based on a 1m DEM of 2019 LiDAR data, defined in the model using a 5m grid. Modifications are made in the form of breaklines to improve representation of the base topography around structures and to reinforce road elevations and drainage lines.

A breakline enforcing the embankment centrelines appears to be sampled from the LiDAR data. A number of locations were noted along the railway where the breakline continued across waterway crossings but where the LiDAR data had filtered out the bridge deck. This has resulted in the road breakline sampling the creek bed/banks. Where these crossings have been represented as culverts, there is a double accounting of flow through the waterway area with flow occurring in both 1D and 2D domains. This is described in more detail under the Structures section of this review.

Materials

Based on a visual inspection of the land use delineation against available aerial imagery, the mapped land uses (materials) are generally appropriate and mapped to a sufficient level of detail for the purposes of the assessment.

Roads have been modelled with a Manning's n of 0.011 which is outside of the range typically applied. It is noted for calibration runs the roads Manning's n value was set to 0.015 so it is not clear why it was lowered for design simulations.

The materials layers are used to set the rainfall losses for the parts of the model to which direct rainfall is applied. Material ID 110 corresponds to mown grass but has been attributed an impermeable loss value. This is discussed further in the section below on External Boundaries.

Some minor inconsistencies were noted between modelled Manning's n values and those quoted in Table 15 and Figure 4 of the AECOM report. For example, the near shore / beach area has a modelled Manning's n of 0.025 but this value is not listed in Table 15 and appears to be a different value in Figure 4. These should be reviewed for consistency.

Structures

Seven bridges have been represented in the model using TUFLOW's layered flow constriction feature. These represent significant bridges along the Bruce Highway and adjacent railway line.

It is not stated in the report how the layered flow constriction form loss coefficients were derived. Typically these would be derived in accordance with publications such as *Hydraulic Design of Waterway Structures* (Austroads, 2019). The form loss values for the sub structure (piers) appear reasonable and are within expected ranges. No form loss values are applied for layer 3 which represents bridge railings. Usually a nominal form loss is applied to represent energy losses associated with this part of the structure.

The model includes 103 culverts modelled as nested 1D elements. No issues were identified with the 1D elements but it was noted that a small number of culverts conveying drainage through the railway line were not obstructed in the 2D domain. This can lead to a double accounting of flow. An example of this near the Bruce Highway crossing of Hencamp Creek is shown in Figure 4.1 below. The magenta lines show bridge structures appropriately modelled in 2D as layered flow constrictions. Breaks in the highway/railway allow flow to pass through the flow constriction. Culverts modelled in 1D are shown as black arrows. Where culverts are modelled, the embankment through which they pass should be represented in the 2D component of the model. In this way, flow can then only pass through the 1D culvert or over the top of the embankment within the 2D domain. Figure 4.1 highlights three locations (blue circles) where the embankment has been removed through the LiDAR filtering process but where there is a modelled culvert present.

The double accounting of flow can lead to an understatement of upstream flood levels. This would be most pronounced for smaller to moderate events when the railway is not overtopped. It is recommended that road embankments are included in the 2D domain at all locations where there is a culvert modelled in 1D.

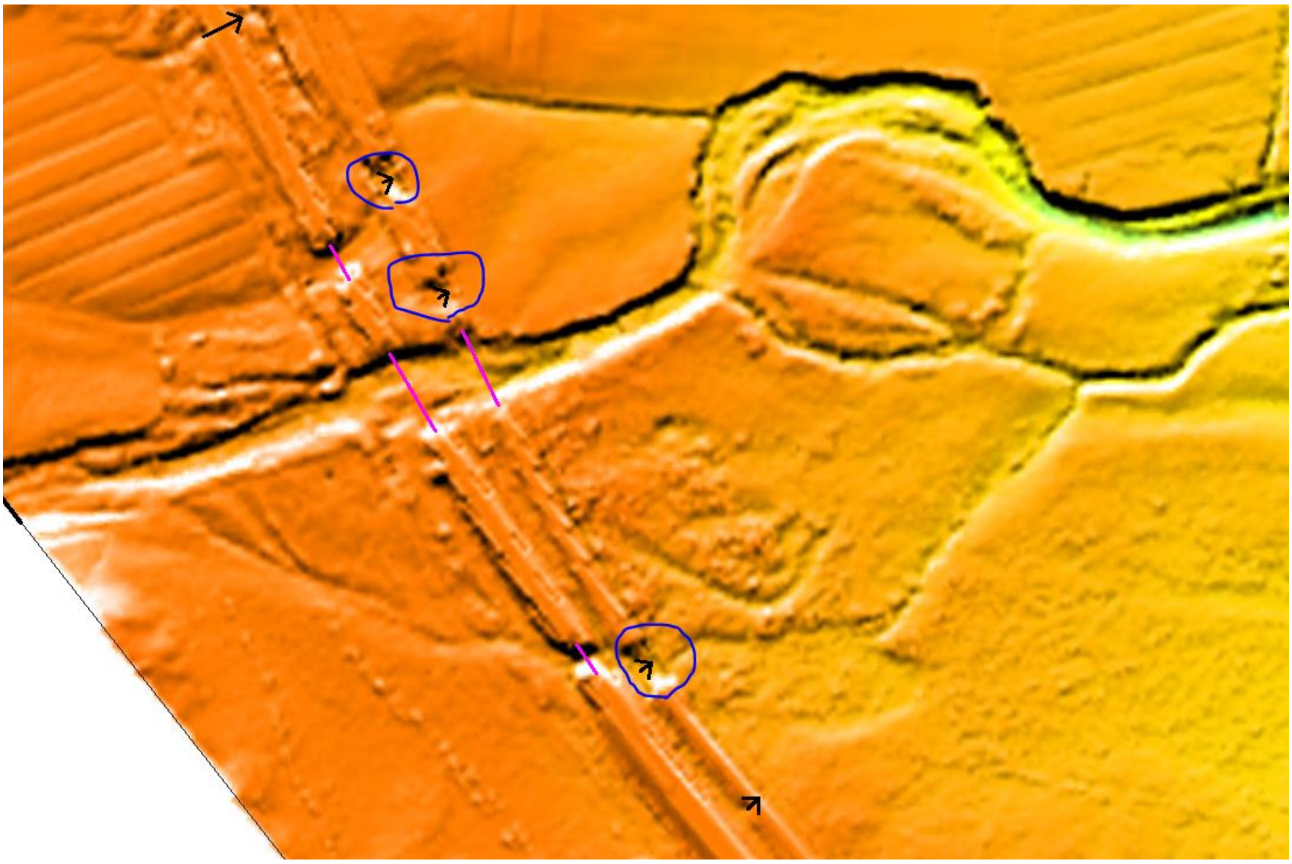


Figure 4.1 Culvert Structures with Missing 2D Embankments near Hencamp Creek

A number of pits and pipes are included in the model within the urban parts of Balgal Beach. TUFLOW can automatically create manholes at pipe junctions for energy loss calculations. AECOM has disabled this function and has digitised manhole locations. The default Engelund loss approach has been applied to these digitised manholes. Whilst a significant number of manholes are specified by AECOM, the disabling of the automatic creation of manholes means that some pipe junctions will not include these energy losses. Overall this will have minimal bearing on the outcomes of the assessment. It is assumed that IDs, dimension data and spatial locations of pit elements has been correctly assigned to TUFLOW as per the supplied network data. A review of the base dataset is outside of BMTs scope.

Head loss verification has been undertaken on the combined effect of the road and rail bridges at the two major crossings of Rollingstone Creek and Hencamp Creek. These were undertaken for the 1% AEP event using a separate 1D HEC-RAS model. The resulting head losses are very similar between the two modelling approaches.

External Boundaries

The model downstream boundary is configured as a water level vs time (type HT) boundary snapped to the active code boundary. Three additional normal depth (type HQ) boundaries are applied along the northern boundary of the catchment to enable flow to discharge from the model into the neighbouring catchment to the north.

The external inflow boundaries are configured as a combination of type QT, type SA and direct rainfall boundaries. Checks on the boundary locations against the hydrologic model subareas show that the schematisation of the boundaries is appropriate and all upstream hydrologic flows are accounted for.

Direct rainfall is applied across the majority of the hydraulic model domain. Hydrologic model inputs are correctly not applied within the area represented by direct rainfall and the direct rainfall extent generally matches the sub-catchment boundaries in which it replaces. The direct rainfall losses (initial and continuing) are applied through the tmf file. Losses for impermeable land use types are specified within the tmf and do not vary with event. Losses for permeable land uses are allocated to a variable which is specified within a separate TUFLOW read file (trd) and varies with event AEP and duration.

When checking the applied losses for land use categories it was noted that land use ID 110 corresponds to 'mowed grass' but has been allocated impermeable initial rainfall losses that do not vary by event. Land use ID 110 represents approximately 8% of the model domain so adoption of impermeable type rainfall losses may overstate runoff from this land use type.

Output Settings

A 'Map Cutoff Depth' of 0.1m has been applied within TUFLOW. The 'Map Cutoff SGS' approach is also set to 'Exact' which in effect is also a cut off depth as the elevation sampled exactly at each cell centre is used as the elevation below which the cells are shown as dry. Depth in the cell is measured from the cell minimum elevation as sampled by SGS. Therefore, whilst every cell receiving direct rainfall is wet, if the depth in the cell remains below the elevation sampled at the cell centre, the cell is mapped as being dry. The higher of these two cutoff depths is applied within the model.

The maximum velocity cutoff depth is set to zero (default value in TUFLOW is 0.1). This will track the maximum velocity irrespective of the depth of water and can potentially result in mapping showing high velocities for shallow depths. Overall this is considered a conservative approach but uses should be aware that this setting is applied.

It is noted that TCC has requested that map outputs are post processed to exclude depths below 0.1m except where velocities exceed 0.8m/s. AECOM has not applied the additional velocity consideration for results filtering and state their rationale in Section 4.1. From a hydraulic output perspective, BMT is satisfied that suitable cut off criteria have been applied.

Model Calibration

The hydraulic model was calibrated to two historic events which occurred in January/February 2019 and April 2014. One stream gauge was present in the catchment and has been used in the assessment to compare modelled and recorded flood levels.

As for the hydrologic calibration, the 2019 event hydraulic calibration shows a generally good agreement to the timing of recorded flood peaks. A good match is achieved to the largest flood peak although some of the smaller peaks are overstated in the model compared to recorded data. Figure 8 in the AECOM report shows the location of three debris survey points which the report states as having surveyed flood levels. The surveyed and modelled flood levels are not quoted at these locations. It is recommended that this comparison is provided in the report, albeit noting that debris marks have a degree of uncertainty associated with them.

In the 2014 event, the hydraulic model overpredicts the peak flood level at the Rollingstone Creek Gauge by approximately 0.6m. The timing of the peak shows a good match.

BMT acknowledges the limited calibration data available for the assessment, in particular the rainfall data applied in the hydrologic model. Based on the two events modelled there is potentially a tendency for the model to overstate peak flood levels for small to moderate events. However it is difficult to draw firm conclusions due to the limited available data. Overall, in BMT's opinion a reasonable calibration has been achieved for the purposes of the flood study which is focused on the magnitude and timing of the flood peak. The potential tendency to overstate flood peaks can be considered precautionary with regard to the modelling outcomes.

4.4 Summary of Hydraulic Model Observations and Recommendations

Table 4.1 Hydraulic Model Development and Calibration Summary

ID	BMT Observation	BMT Recommendation
4.1	Naming conventions are not in strict accordance with requested naming convention by TCC	For consideration by TCC. In BMT's opinion the adopted naming remains clear, logical and allows TCC to easily identify it is a Balgal Beach model. We do recommend that a run ID is incorporated into the model name.
4.2	The small size and of the model and the fast simulation times meant that it would have been feasible to include all upstream subareas as local TUFLOW inflows.	This would have provided the additional benefit of having the upstream boundary located further away from the Bruce Highway
4.3	Breaklines used to enforce road crest elevations, in places capture the watercourse bed/banks where the LiDAR data has been filtered to remove bridges.	This becomes an issue when a 1D nested culvert is modelled. See Recommendation 4.7.
4.4	The Manning's n of 0.011 for roads is very low and does not match the value used in model calibration.	Observation only. Changing this value is not expected to have any notable effect on outcomes.
4.5	Minor inconsistencies noted between modelled Manning's n values and those quoted in Table 15 and Figure 4 of the AECOM report.	Review and update for consistency. See material ID 113 for example.
4.6	No form loss values are included within layer 3 of the layered flow constrictions (representing guard rails).	A form loss value should be included but not expected to have any notable bearing on modelling outcomes.
4.7	A double accounting of flow occurs at a number of the cross drainage railway crossings with flow passing through the 1D modelled culverts and through the 2D domain.	Affected locations should have embankments enforced in the 2D domain.
4.8	Land use (material) ID 110 represents a pervious land use type (mowed grass) but has been allocated rainfall initial losses associated with an impervious land use.	Given the relatively large proportion of land covered by this land use (8%), we recommend it is allocated a permeable rainfall loss or otherwise explained.
4.9	Results filtering is not strictly in adherence with TCC requested filtering criteria as it omits the velocity component.	Cutoff depth applied appears reasonable but TCC to review against requirements.
4.10	Model calibration to the January/February 2019 event mentions three surveyed debris mark locations but does not present modelled or surveyed flood levels.	Recommended that this comparison is included in the report.

5 Determination of Design Floods

5.1 Overview

The approach to design flood estimation applied by AECOM in the flood study, is based on the ARR2019 guideline. A single stream gauge on Rollingstone Creek is present within the catchment. Whilst AECOM has undertaken a flood frequency assessment on the gauged record, the record is short (7 years) and no firm conclusions can be drawn from the assessment. Therefore, the approach to design flood estimation relies upon model simulations using the hydrologic and hydraulic models developed in the assessment.

The remainder of Section 5 sets out BMT's review of the design flood estimation including the design event selection process for model simulations.

5.2 Design Event Simulation

Design Parameters

A single IFD location appears to have been used in the hydrologic model. This generates rainfall depths that match those quoted in Table 12 of the AECOM report. The rainfall depths in the direct rainfall component of the TUFLOW model are notably higher than those quoted in Table 12. For example, the 1% AEP, 3 hour rainfall depth is stated as 187mm in Table 12 (and XP-RAFTS) and is 211mm in TUFLOW. Upon inspection of the IFD dataset there is a relatively steep gradient in the design rainfall depths with values decreasing with distance inland. The IFDs applied in TUFLOW (direct rainfall) are therefore appropriate.

An inconsistency was also noted with regard to the modelled PMP rainfall depths. The 3 hour PMP depth in XP-RAFTS and TUFLOW (direct rainfall) was 591mm and 640mm respectively. The PMP represents a catchment average areal rainfall depth and so typically only a single depth is applied across the area of interest unless factored using the topographic adjustment factor. Details of the PMP rainfall depth calculation are not included in the report but it is recommended that they should be. Given the extreme nature of the PMP and resulting PMF, such inconsistencies are not expected to have any notable bearing on the project outcomes. The way in which the PMP was applied in TUFLOW and XP-RAFTS was checked and found to use a consistent temporal pattern.

The AECOM report (Table 11) states that an areal reduction factor (ARF) has been applied based on the 'East Coast North' region. The model files show that no ARF has been applied i.e. the ARF value is 1.0. An ARF of 1.0 is a conservative approach and in BMTs opinion is suitable for the assessment. An ARF of 1.0 is also consistent with what has been applied in the direct rainfall model. It is recommended the report is updated to make it clear that no ARF is applied.

An ensemble approach to temporal patterns has been applied as set out in ARR2019. Point temporal patterns have been applied. In accordance with ARR2019, if the catchment area is greater than 75km^2 then areal temporal patterns should be applied. The Balgal Beach total modelled area (in XP-RAFTS) is 138km^2. However this total area is comprised of a number of smaller catchments which drain to the ocean. The largest catchment, Rollingstone Creek, has a catchment area of approximately 75km^2 to the Bruce Highway. Given that the other catchments are smaller than this, BMT considers the use of point temporal patterns is acceptable.

With regards to rainfall losses the approach taken follows that given in ARR2019 whereby an initial storm loss is converted to an initial burst loss by accounting for pre-burst rainfall. For permeable areas an initial storm loss of 60mm is reported for both hydrology and hydraulic (direct rainfall) components of the modelling. The continuing loss is reported as being 2mm/h for permeable areas.

These loss values differ from that specified in the ARR2019 datahub which show a storm initial loss value ranging between 40mm to 50mm and a continuing loss of 4mm/h.

There is minimal explanation in the report as to why a higher initial storm loss value has been applied compared to what is in the ARR Datahub, noting that both calibration events had lower initial losses. However, given the relatively minor differences in storm loss and the significance of the pre-burst depths (see Table 5.1), this is not expected to have any significant bearing on model outcomes.

The applied pre-burst depths also differ between the XP-RAFTS and the TUFLOW (direct rainfall) models. This in turn applies different initial burst loss values to the respective models. This is due to the pre-bust depths being sampled from a different nominal location for the two respective models. Checks by BMT show that the sampled locations are representative of the respective areas covered by the two models. The pre burst depths and burst losses are shown in Table 5.1. It can be seen that pre burst depths are significant for the 90, 120 and 180 minute durations meaning that the resulting initial burst loss (given by 'initial storm loss' minus 'pre burst depth') is low for these durations.

The change in continuing loss from the ARR datahub value of 4mm/h to an adopted value of 2mm/h is closer to the value used in model calibration, although remains higher. Typically the continuing loss value would be informed by the model calibration. It is recommended that AECOM provides further rationale for use of a higher continuing loss than that which achieved model calibration.

Table 5.1 1% AEP Pre Burst Depths

Duration (min)	Pre Burst Depth (XP-RAFTS) (mm)	Resulting Initial Burst Loss (XP-RAFTS) (mm)*	Pre Burst Depth (TUFLOW) (mm)	Resulting Initial Burst Loss (TUFLOW) (mm)*
60	26.2	33.8	13.9	46.1
90	54.0	6.0	47.9	12.1
120	55.3	4.7	70.7**	0
180	69.0**	0	111.1**	0

***Based on an Initial storm loss of 60mm**

****This is greater than the storm initial loss of 60mm so the resulting burst initial loss is 0mm**

ARR2019 recommends an initial burst loss of 0mm and a continuing loss of 1mm/h when modelling a PMF event. These recommended values have been used with the direct rainfall applied in TUFLOW. Within the AECOM report (Table 13) and the XP-RAFTS model, a PMF initial loss of 20mm and a continuing loss of 0.25mm/h have been applied. It is not stated why these different values have been used but generally these should be consistent between XP-RAFTS and TUFLOW. Given the extreme nature of the PMF event, it is not considered that amending these values to be consistent will have any notable bearing on the modelling outcomes.

The downstream boundary is specified as a constant level set at MHWS (1.2mAHD) for all design events. Use of MHWS is in accordance with the TCC Guideline.

Critical Duration / Event Selection

An ensemble approach to modelling rainfall temporal patterns has been applied in the design flood modelling. This is in accordance with ARR2019. The ensemble approach relies upon a representative average ensemble member being selected for a given AEP/Duration. This representative ensemble member may vary across the catchment being modelling and so its selection can be based on assumptions and judgement. BMT has reviewed the event selection process undertaken by AECOM and makes the following comments/observations.

- Identification of the critical durations and temporal patterns has been undertaken using the hydraulic model. This has involved running full ensembles (10 events) for each duration/AEP combination and analysing the flood levels in every grid cell. It results in a significant number of simulations but is feasible due to the rapid simulation times of the model (typically less than 5 minutes).
- The process results in a peak design flood elevation surface effectively based on a statistical analysis of results in keeping with the ARR2019 approach at every grid cell. For a given AEP, this process first identifies the median flood level for each duration in every grid cell and then generates a flood surface based on the maximum of the median flood levels. A drawback of the approach is that a flood surface for any given AEP may be composed of results from many hydraulic model simulations and can impact the usability of the model from a practical point of view. Given the rapid simulation times, running many hydraulic simulations is unlikely to be an issue. However this can cause complications when using the model for impact assessments. It is recommended that TCC/AECOM provide supplementary guidance on how to select appropriate events for flood impact assessments to avoid a variety of approaches being applied by third parties.
- The report does not state, but it is assumed that, the process for deriving other gridded flood surfaces (velocity, hazard etc) is the same as that used for peak level (a max of the median approach). For a given location and for a given AEP, it is possible that different model simulations have generated the peak flood level and the peak of another output variable eg velocity. This can cause complications when using the model outputs for purposes beyond the flood study. It is recommended that the supplementary guidance referred to in the above point also includes selection of events for outputs other than peak level.

Sensitivity Analyses

Climate Change

A sensitivity assessment has been undertaken on climate change for both the 2% and 1% AEP in accordance with the RFQ. Relative Concentration Pathway 8.5 (RCP 8.5) has been used for the assessment which is also in accordance with the RFQ. Rainfall intensity has been increased by 15.4% and an allowance of 0.8m has been made for sea level rise (SLR).

The mapped results are in agreement with expectations and BMT has identified no issues.

Joint Probability Zone

AECOM has undertaken a pre-screening analysis in accordance with Book 6, Chapter 5 of ARR2019 for the consideration of riverine and oceanic flooding. This has been done for the 1% AEP and the 1% AEP with climate change.

Changes to rainfall and tidal boundary parameters (as per reporting) for the joint probability assessment scenarios were confirmed to be implemented correctly in modelling files, via alternative boundary conditions databases and TUFLOW logic. It is noted from the results that the defined storm tide level in the Townsville City Plan is greater than the fully dependent flood surfaces within the defined JPZ. Therefore existing planning provisions effectively already account for any uncertainty in choice of downstream boundary condition. BMT therefore agrees with AECOMs statement that a full design variable method is not warranted for Balgal Beach. Overall, the approach is consistent with ARR2019.

Structure Blockage

A blockage assessment has been undertaken which is in accordance with ARR2019. This assessment has been undertaken on modelled bridges, culverts and pipes for both the 50% and the 1% AEP events.

The reported bridge blockage factors for the 1% AEP and the 50% AEP of 20% and 10% respectively are applied correctly within the model. Likewise, the reported culvert and pipe blockage factors for the 1% AEP and the 50% AEP of 25% and 15% respectively are applied correctly within the model.

BMT notes that in ARR2019 the ‘design blockage’ is the blockage condition that is most likely to occur for a given storm and that an ‘all clear’ (no blockage) scenario should be the sensitivity test. In the AECOM study, the sensitivity test is the one with the design blockage and the all clear case has been adopted when producing the final flood surfaces. However, we understand the blockage scenario was specified as a sensitivity assessment in the RFQ.

In BMT’s opinion, the blockage assessment has been undertaken in accordance with TCC’s requested approach and blockage values are reasonable for the purposes of the sensitivity assessment. When using the results of the study to inform planning levels, the results of the blockage sensitivity test should be reviewed. Any areas where water levels are particularly sensitive to structure blockage should consider the water level under the blockage scenario for planning purposes.

Design Simulation Results

A comprehensive set of design results are included in a separate volume of the flood study report. Mapping includes flood level, depth, velocity, classified hazard (AIDR, 2017), and classified hazard in accordance with the TCC flood hazard overlay.

The labelling of the digital results generally conforms to TCC’s requested naming conventions but is subject to the same comments as described in Section 4.2 on model naming conventions.

The results have also been analysed to provide information as follows:

- Counts of buildings within each AEP
- Water depth of main roads at selected crossings
- Commentary on what AEP inundates community buildings and infrastructure.

5.3 Comparisons to Previous Assessments

In April 2008 the Balgal Beach Infrastructure Master Planning report was prepared for the former Thuringowa City Council. This study included the development of base case flood models (XP-RAFTS and MIKE FLOOD) which were used to map the 20, 50, 100, 500 year and PMF events. Prior to the current study, the 2008 study represents the most recent flood modelling and mapping undertaken for the Balgal Beach catchments. The modelling utilised a 15m grid with nested 1D channels. Whilst not stated, it is assumed the hydrology was based on ARR1987.

BMT has undertaken a broad comparison so the 1% AEP (100 year ARI) results between the 2008 study and the current study and this is described below.

In general, the new flood levels are higher than those from the 2008 study. Within channelised parts of the Rollingstone Creek channel the new results are up to 2.5m higher in places. Within the urban parts of Balgal Beach, the differences are less pronounced with a mixture of increased and decreased flood levels. A notable difference is the increased extent of the new results compared to the original results. A large part of this is due to the use of a direct rainfall approach which will generate flow in flow paths not picked up by previous modelling.

Overall it would be expected that flood levels are different due to the following principal factors:

- A revised hydrologic approach (ARR2019 vs ARR1987)
- Updated model topography (more recent LiDAR of higher resolution)
- Use of direct rainfall modelling across the lower catchment
- Advancements in hydraulic modelling (finer grid resolution and improved solution schemes).

The principal changes implemented through use of ARR2019 are updated design rainfall depths and a revised approach to temporal storm patterns whereby an ensemble of ten patterns is now modelled and a representative average pattern/s selected.

With regards to design rainfall, the latest IFD derived rainfall depths vary against the older depths but there is no obvious trend. For example, in a 3 hour storm, which is noted as being critical across parts of the study area, the current 1% AEP rainfall depth in upper parts of the catchment is 187mm compared to the previous depth of 213mm. However, in lower parts of the catchment the current 1% AEP 3 hour rainfall depth is 214mm compared to 199mm previously

With regards to temporal patterns, the previous ARR1987 approach was to use a single storm temporal pattern referred to as an AVM (Average Variability Method). The intention of both the ensemble and AVM approaches is to preserve probability neutrality i.e. so that a 1% AEP rainfall approximates a 1% AEP resultant flood. However, the AVM approach has limitations in that it does not account for how temporal patterns interact with catchments to produce peak flows and hydrographs. ARR2019 better accounts for this by modelling an ensemble of varying temporal patterns. In BMT's experience, use of the ensemble approach typically results in lower peak flood estimates although it is recognised that this may not always be the case and that it can be difficult to isolate the effects of the temporal pattern approach without specific sensitivity testing.

In conclusion, there are notable differences in peak flood levels between the two respective studies but without further investigation it is not possible to identify the contributing factors to those differences except at a high level. The updated modelling is in accordance with the latest guideline (ARR2019), uses the most recent and complete topographic data and using modelling resolutions and techniques that allow for much improved flood mapping.

5.4 Summary of Design Flood Estimation Recommendations

Table 5.2 Design Flood Estimation Summary

ID	BMT Observation	BMT Recommendation
5.1	An inconsistency was noted with regard to the modelled PMP rainfall depths in XP-RAFTS and TUFLOW (direct rainfall). No explanation is provided as to why they differ.	The report should document the calculated PMP depth and how any spatial pattern was determined. However the inconsistency is not expected to have any bearing on the study outcomes.
5.2	An ARF of 1 (no reduction) is applied. The report states ARFs from the East Coast North region are applied but this is not the case.	Update report to state an ARF of 1.0 is applied.

ID	BMT Observation	BMT Recommendation
5.3	A PMF initial loss of 20mm and a continuing loss of 0.25mm/h is applied in XP-RAFTS which differs from that applied in TUFLOW.	Review for consistency. A PMF will generally adopt an IL of 0mm and a CL of 1mm/h based on the ARR2019 guideline.
5.4	The adopted continuing loss of 2mm/h is greater than that determined through model calibration.	It is recommended that AECOM provides further rationale for use of a higher continuing loss than that which achieved model calibration
5.5	The approach to simulate all ensembles and durations to generate a flood surface of a given AEP can complicate approaches taken for flood impact assessments.	TCC/AECOM provide supplementary guidance on how to select appropriate events for impact assessments

6 Other Considerations

6.1 RPEQ Signoff

The RFQ requests that the flood modelling study is completed by a suitably qualified and experienced Registered Professional Engineer of Queensland (RPEQ). As such the report should include signoff demonstrating RPEQ oversight.

6.2 Other Considerations Summary

Table 6.1 Summary of Other Considerations

ID	BMT Observation	BMT Recommendation
6.1	No RPEQ signoff included in report	Add RPEQ signoff

7 Conclusions

This peer review report has documented the review findings for the Balgal Beach Flood Study undertaken by AECOM as part of Townsville City Council's Townsville Flood Modelling and Mapping Project.

Overall the study was found to generally follow best-practice modelling approaches and techniques and conform with approaches within ARR2019.

Observations and recommendations have been made by BMT on key aspects of the study with a summary of these tabulated in each section of this report.

One issue of potential significance was noted with regard to the representation of cross drainage through the railway which can in turn impact upon flood levels at the Bruce Highway. Remaining identified issues were of a minor nature, the majority of which relate to requests for clarifications within the report.

8 References

Austroads (2019) Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures June 2019.

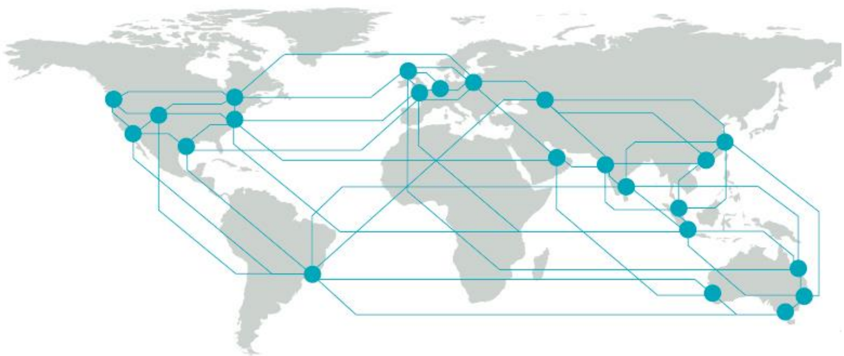
AECOM (2022) Base-line Flooding Assessment – Balgal Beach Flood Study – Volume 1 and Volume 2 – Report (Revision A). Prepared for Townsville City Council, January 2022.

Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2019, Australian Rainfall and Runoff: A Guide to Flood Estimation, Commonwealth of Australia

Maunsell Australia (2008) Balgal Beach Infrastructure Master Planning, Draft Report. Prepared for Thuringowa City Council.

TCC (undated) Request for Quotation: Townsville Recalibrated Flood Modelling and Mapping – Magnetic Island & Balgal Beach, RFQ002345.

TCC (2020) SC6.7.4 Attachment 1 - Guidelines for Preparation of Flood Studies and Reports, Townsville City Plan Version 2020/03



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