Peer Review of Ross River Flood Study

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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 modelling contract undertaken for the **Ross River and Surrounds** as presented within the *Ross River Flood Study Base-line Flooding Assessment* by AECOM (AECOM, 2021).

1.2 Supplied Data

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

- Ross River Flood Study Base-line Flooding Assessment Volumes 1 and 2, Revision A dated 14 October 2021 (AECOM, 2021)
- Request for Quotation: Extract from 'Townsville Recalibrated Flood Modelling and Mapping – The Ross River and its Surrounding Areas', Particulars of Consultancy Services (DRAFT) Phase 1. (TCC, undated)
- Hydrologic Models:
  - Ross River Dam Hydrology: RORB model files associated with supplied report *Ross River Dam Hydrology Update Final v1* prepared by Hydrology and Risk Consulting (HARC, 2021)

    - XP-RAFTS model files for the following six catchments (Mundy Creek, Northward Creek, Ross Creek, Ross River (downstream of dam), Sandfly Creek, Stuart Creek).
- A hydraulic TUFLOW model: control file RR_~s1~_~e1~_~e2~_~s2~_~e4~_~s3~_~s4~_001.tcf, and associated TUFLOW model log.

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;
- Commentary on differences in flood levels from previous assessments (which were developed based on the Australian Rainfall and Runoff 1987 guideline (ARR1987) with hydraulic modelling undertaken using MIKE FLOOD software); 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 observation 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 Ross River Flood Study has developed a single hydraulic model with a fixed 5m resolution grid using TUFLOW HPC software for the Ross River catchment and key tributaries downstream of the Ross River Dam (RRD). This model consolidates numerous separate hydraulic models previously developed for different parts of the catchment.

Inflows to the hydraulic model are generated from a combination of multiple hydrologic models and from rainfall applied directly to the hydraulic model domain. A distinction is made between hydrologic modelling of the catchment area upstream of the RRD and hydrologic modelling of catchments downstream of the RRD. The former is modelled using a single RORB model whereas catchments downstream of the RRD are modelled using six separate XP-RAFTS models, each representing a different tributary.

A calibration exercise has been undertaken with the hydrologic RORB model (representing the catchment upstream of the RRD) calibrated to two historic events in January/February 2019 and March 2012. Both of these events included outflows from the dam.

Calibration of the XP-RAFTS models was undertaken only if there was available stream gauging data for historic events. For catchments with no or unreliable streamflow data (Mundy Creek, North Ward and Sandfly Creek), calibration was not undertaken and a verification, using either the Rational Method or Regional Flood Frequency Estimation (RFFE), was undertaken. The remaining three catchments were calibrated to the January/February 2019 event and one other suitable event.

Calibration of the hydraulic TUFLOW model was also undertaken for the January/February 2019 and March 2012 flood events along with a further event which occurred in February 2018. The February 2018 event had no outflow from the RRD but localised rainfall caused minor flooding in the lower Ross River catchment.

The calibrated models were then 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 event modelling uses the approach set out in the ARR2019 guideline (Ball et al, 2019).

Due to the significant effect of the RRD on downstream flood behaviour, AECOM has undertaken two general categories of design hydraulic model simulation:

- Long duration simulations of the critical outflows from the RRD.
- Short duration simulations for obtaining critical local catchment flows for catchments downstream of the RRD. This includes direct rainfall onto urban parts of the catchment.

Peak flood outputs from the two approaches have then been enveloped to obtain the maximum result. Of note, the long duration simulations only contain inflows to the hydraulic model representing RRD outflows. There are no local catchment inflows or direct rainfall inputs within the lower catchment.

The remainder of this report sets out the key findings from our peer review of the flood study covering both the technical setup and quality of the hydrologic and hydraulic models as well as the overall modelling approach.

The structure of the peer review generally follows the structure of the flood study under review. Model development and calibration is initially reviewed followed by design flood modelling (including use of ARR2019) techniques. Where applicable, review commentary is provided on the change in flood levels compared to previous assessments.

3 Hydrologic Model Development and Calibration

3.1 Background

As described in Section 2, there are two parts to the hydrologic modelling as follows:

- Derivation of RRD outflows from hydrologic modelling of the upstream catchment using a RORB model along with a RRD gate operations module.
- Derivation of lower Ross River catchment (downstream of the dam) runoff including all main tributaries using six XP-RAFTS models.

The RORB and XP-RAFTS models were developed and/or updated as part of the '*Review of Hydrological Methods for Townsville Flood Modelling*'. This includes the following relevant phases:

- Phase 3 – Catchment Simulations for Test Catchments (HARC, 2018): This study developed/updated the upper Ross River Dam model and the lower Ross River XP-RAFTS model.
- Phase 4 – AR&R 2019 Hydrologic Model Updates (AECOM, 2019): This study developed/updated XP-RAFTS models for various catchments including Mundy Creek[1], North Ward, Ross Creek, Stuart Creek and Sandfly Creek.

Extracts from the Phase 4 study relevant to the five models XP-RAFTS models are included in Appendix B of the AECOM flood study report.

The flood study refers to refinements/updates made to these hydrologic models. These refinements/updates are generally as follows:

- To run additional calibration events (for the Phase 3 models) as the significant flood event of January/February 2019 occurred after Phase 3 was completed.
- To refine the models to facilitate linkage to the TUFLOW hydraulic model such as ensuring appropriate model inflow locations and to better align subcatchments to accommodate a rain on grid approach within TUFLOW.

A review of the suite of studies/models delivered under the *Review of Hydrological Methods for Townsville Flood Modelling* is not part of the scope of this peer review. As such, our peer review of the hydrologic modelling is limited to its overall suitability and defensibility of its implementation within the Ross River Flood Study Update.

3.2 Hydrologic Model Review

3.2.1 General Comments – Upper Model

The Upper Model (RORB) was updated for the Flood Study by HARC who then provided the updated model and results to AECOM. A standalone report has been prepared by HARC '*Ross River Dam Hydrology Update*' (HARC, 2021) which documents the RORB model updates and outputs.

BMT understands the RORB subcatchment areas and parameters are unchanged from those used in the Phase 3 update. BMT has undertaken basic checks of the subcatchment areas. The modelled area

[1] Also referred to as Captains Creek.

of 762.4km^2 compares against BMT's estimate of the catchment area of 758.9km^2 (less than 1% difference) and so all upstream catchment area is accounted for.

The calibration of the upper model to the January/February 2019 event was undertaken as a calibration to the dam outflow. This involved incorporating the historic dam gate operations into a RORB 'gateops' module. The results as presented by HARC demonstrate a good match to recorded dam outflows. Model calibration was also undertaken for the flood event of March 2012. A reasonable calibration to the peak and volume of the dam outflow was achieved but the modelled peak outflow occurs approximately 8 hours before the recorded peak outflow. Given the limitations of the data (recorded dam outflow was inferred from dam level and dam operation rules) and that the magnitude of the 2012 outflow was approximately a quarter of that of the 2019 event, the overall calibration is considered satisfactory.

3.2.2 General Comments – Lower Models

The lower models comprise six separate XP-RAFTS models. Checks were performed by BMT on the overall modelled catchment areas against catchment areas in supplied GIS files and showed no notable discrepancies (see Table 3.1).

Table 3.1 Rafts Area Checks

Model	Model Area (ha)	GIS Area (ha)	difference
Mundy Creek	901.66	902.25	<1%
North Ward	413.69	414.01	<1%
Ross Creek	2,613.49	2,612.26	<1%
Ross River D/S	8,126.40	8,050.22	<1%
Stuart Creek	6,446.12	6,450.87	<1%
Sandfly Creek	4,385.44	Not supplied	n/a

It was noted by BMT from the AECOM reporting that the different XP-RAFTS models do not have a single consistent approach to the way in which they apply hydrologic routing; two models apply simple channel lagging (Mundy Creek, Sandfly Creek) and the others apply channel routing. Given that effort has been made to either calibrate or validate each model, these inconsistencies are not expected to have any notable impact on study outcomes.

The calibration of the lower models is documented within Phases 3 and 4 of the *Review of Hydrological Methods for Townsville Flood Modelling* and so a review of the calibration is outside the scope of this current review. Whilst extracts from the Phase 4 study are provided in Appendix B of the AECOM flood study report and cover five of the XP-RAFTS models, there is no similar extract for the lower Ross River model. Presumably this is because it was updated under phase 3 of the assessment. It is recommended that this is clearly stated so the omission does not look like an oversight.

It is also noted that the current study has updated the XP-RAFTS models as documented in Section 2.2 of the AECOM report. The subsequent section on hydrologic model calibration then simply refers to extracts from the Phase 4 study which have been included in Appendix B. The presented model calibration therefore pre-dates the model updates. BMT understands that the updates are of a minor nature and may not have any notable bearing on the model calibration. Subject to this being the case, BMT recommends that a statement should be included in the report (Section 2.3.1) which states that the model calibration/verification has not been revisited following these minor refinements.

3.3 Summary of Hydrologic Model Observations and Recommendations

Table 3.2 Hydrologic Model Development and Calibration Summary

ID	BMT Observation	BMT Recommendation
3.1	Inconsistencies between the various XP-RAFTS models with regards to hydrologic routing.	None for current study but should be revisited and standardised in future study.
3.2	No summary provided of the Lower Ross River XP-RAFTS calibration. It is not clear if this model has been calibrated to the 2019 event as the HARC Phase 3 study pre-dates this flood.	Include summary or reference report which documents the outcomes of the lower Ross River calibration to the 2019 event.
3.3	Study has updated hydrologic models but not revisited the model calibration using the updated models.	BMT understands the updates are of a minor nature and may not change the calibration outcomes. We recommend that a statement is included in Section 2.3.1 along the lines of the above.

4 Hydraulic Model Development and Calibration

4.1 Background

The hydraulic model is a new model developed using TUFLOW software, the results of which will replace 8 separate MIKE-FLOOD models previously developed for different parts of the catchment. 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 TUFLOW version at the time of the assessment.

4.2 General Considerations

4.2.1 Overview

A single TUFLOW control file (tcf) is supplied from which all required events can be simulated. The tcf is named as follows:

- RR_~s1~_~e1~_~e2~_~s2~_~e4~_~s3~_~s4~_001.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.

4.2.2 Naming Conventions

TCC has nominated a standardised hydraulic model naming convention to be used on models developed for the Project. The file naming adopted by AECOM broadly meets the naming convention although does not conform exactly. For example, the scenario description is lumped in with the modelled event identifier which then becomes larger than the requested 3 characters. Likewise, event durations are specified in hours and not the requested minutes.

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 Ross River model (or result file).

4.2.3 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. A 'Control Number Factor' of 0.8 has been applied. This is recommended if models have a high number of repeated timesteps. Use of this factor will slow the model simulation times but BMT notes that the simulation times for the majority of runs remain reasonable (less than 24h on a mid range GPU card).

In a test simulations, BMT was able to initialise and run the model with the supplied model files. A BMT repeat simulation of a downstream catchment event (1% AEP, 9h) gave results which matched exactly with those supplied. A further repeat simulation of one of the 1% AEP, 120h event with RRD outflows showed minor discrepancies in the flood extent between the supplied result and the remodelled result. The reasons for these discrepancies are not clear but should be investigated by AECOM as the supplied model does not appear to generate the supplied results using the specified TUFLOW build.

4.3 Hydraulic Model Development and Calibration

4.3.1 Topography

The majority of base topography is formed from a 1m DEM generated from 2016 LiDAR survey. Supplementary topographic grids are then applied representing bathymetry and DEMs for development sites which have come from 2019 LiDAR data. BMT understands that, based on advice from TCC, the 2019 LiDAR is to be treated with caution and the 2016 LiDAR should generally be used in its place for the majority of the model domain. The ordering of the layers applied in TUFLOW is appropriate.

Additional topographic modifications have been made including the use of breaklines to represent the road network layer and reinforcement of the footprints of large buildings.

Three levees are read in as z shapes. Two of these are alongside the Ross River; one upstream of Black Weir on the left hand bank and one upstream of Aplins weir, also on the left bank. The report notes that key levees were enforced in the model based on the 2016 LiDAR data. It is recommended that the source of the elevation data is specified as a comment in the model files.

4.3.2 Materials

Overall the land use delineations show a high level of detail. Much of the land use is urban and buildings have been modelled with a very high Manning's n, typically located within a zone of high Manning's n representing urban blocks. This is a standard approach to modelling buildings within urban areas for flood studies. The Manning's n value used to represent the majority of urban blocks in the model is 0.14 which is higher than the urban residential range within the Townsville Guide (0.04 to 0.1) but within acceptable ranges as specified within ARR2019 (eg 0.1 to 0.2 for low density residential). Buildings themselves are then specified within the urban block with a depth varying Manning's n with n ranging from 0.011 to 0.3.

The tidal waterway of the Ross River has a Manning's n value of 0.055 which is unusually high for a tidal system. Upstream of Aplins weir, the non-tidal waterway has a lower Manning's n of 0.04. The high Manning's n values may introduce a degree of conservativeness in the lower reaches in the form of higher flood levels. However, it is noted from the 2019 calibration that a reasonable calibration has been achieved with these values. BMT is therefore not recommending that these values are changed but just notes that they are high and should be revisited during future model calibrations.

4.3.3 Structures

Key bridges are modelled in 2D using TUFLOW's layered flow constriction feature. Generally bridges are modelled in a standard way and the range of values applied (blockages and form loss values) are within acceptable ranges.

Vickers Bridge (Ring Road) is modelled slightly unusually in that the bridge deck level is included as layer 3 (typically it is layer 2). It appears the reason is to incorporate two separate substructure layers, assumed to represent the piles and piers respectively. The bridge soffit is approximately 24mAHD so significantly above all modelled floods including the PMF. Whilst the modelling approach is unusual, the bridge representation is appropriate.

John McIntyre Bridge on Southern Port Road is a major bridge over the Ross River and is not included in the model. The omission of this bridge is not expected to have any bearing on flood results given its location at the river mouth. It should however be included for completeness.

Head loss verifications to 22 bridges have been undertaken, comparing the head loss calculated in the TUFLOW model to that from independent modelling (HEC-RAS or Hy8). As would be expected, there are differences in head loss values between the various techniques but generally the differences are within a few millimetres. Larger differences occur at some structures which typically have greater absolute head loss values but as a proportion, the difference remains low. It is noted that the head loss across a structure in the TUFLOW model will also be accounting for any losses associated with river bends (if the structure is on a bend) whereas the 1D HEC-RAS model will not capture these additional losses.

There are 508 culverts specified in the model, two of which are irregular shaped with dimensions specified using height width relationship. BMT has undertaken basic spot checks on culvert representations within the model and no issues were identified. All significant cross drainage on all major drainage flowpaths appears to have been accounted for.

Some locations were identified where there is a crossing of a waterway (which is represented in the LiDAR) and where no provision has been made for cross drainage. These are typically minor and will not have any bearing on riverine flood results. An example is shown in Figure 4.1 within the Lavarack Barracks where an SA inflow (blue polygon) is applied upstream of a crossing of a drainage channel. Water will backup behind the cross drainage structure and will spill over or around it, potentially creating new flowpaths.

Our general recommendation is to incorporate a short statement that any third party use of the model at a more localised scale should review the culvert/pipe representations and update if required.

Spot checks on the stability of flow through the more significant culverts showed no instabilities of concern[2].

[2] Based on a simulation rerun by BMT of the 1%AEP, 9 hour event for temporal pattern ID 8752.

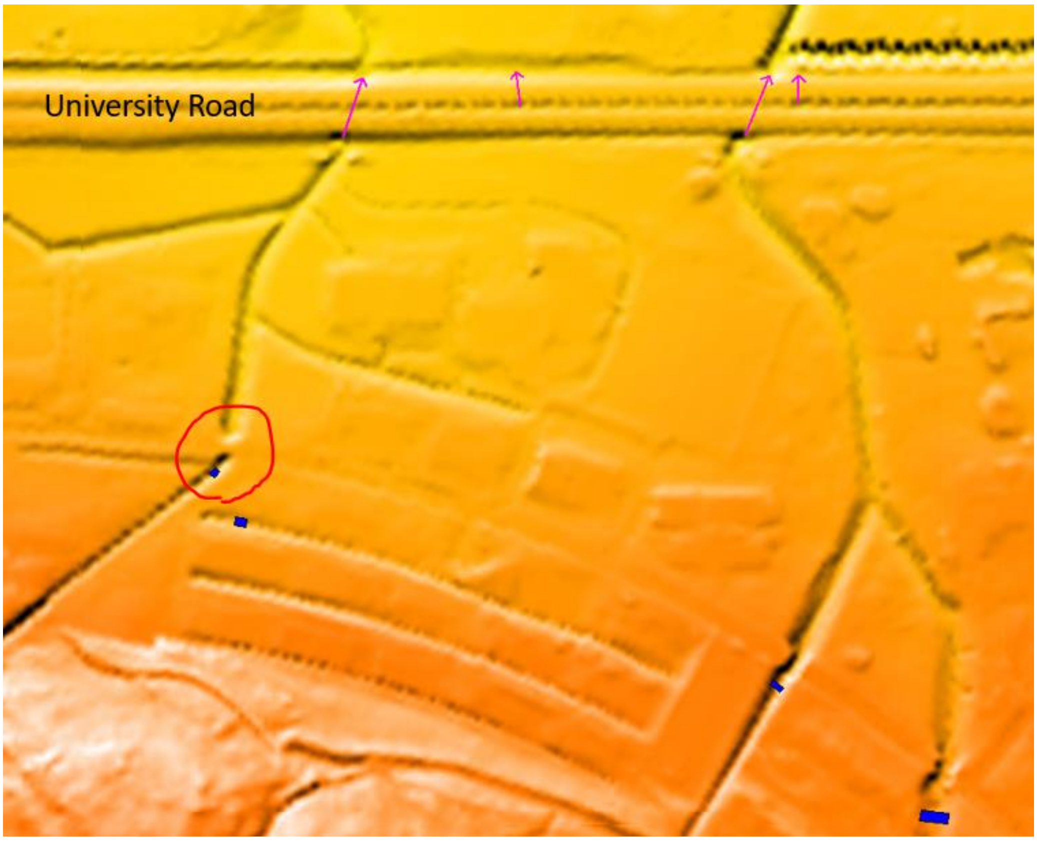


Figure 4.1 Missing Cross Drainage – Lavarack Barracks

A significant number of pits and pipes are included in the model. TUFLOW can automatically create manholes at pipe junctions for energy loss calculations. AECOM has disabled this function and has digitised manhole locations. The default manhole side clearance of 0.3m has been retained by AECOM along with the default Engelund loss approach. Whilst a significant number of manholes are specified by AECOM (1715), 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.

The model includes 7 operational pumps at 3 locations within the model. These have been set up appropriately within TUFLOW although it is noted they will have very little influence on model results.

4.3.4 External Boundaries

Outflow from RRD forms the major external inflow into the TUFLOW model. This is modelled as a flow versus time (QT type) inflow which is appropriate. There are 11 further QT boundaries for total flow inputs from the downstream tributary XP-RAFTS models which enter at the upstream extents of the hydraulic model domain.

There are 437 source-area (SA type) inflow boundaries representing local subcatchment runoff from the XP-RAFTS subcatchments which have applied at locations within the TUFLOW model domain. Each SA inflow is typically applied to a small area within a watercourse. A further 46 local XP-RAFTS inflows are applied directly to the 1D modelled pipe network where there are no open channels.

Direct rainfall is applied across approximately half of the model domain to simulate rainfall onto urban areas. Hydrologic model inputs are not applied within the area represented by direct rainfall. The direct rainfall losses (initial and continuing) are applied through the tmf file using variables defined in a separate trd file with different sets of IL and CL values for IM (impervious), PN (undeveloped area outside of urban footprint), PU (pervious urban), PL (not specified but corresponds to compacted bare soil land use types eg dirt roads).

BMT agrees that the different rainfall loss categories are appropriately allocated to the different land uses.

As two different methods are used to apply the same ARR2019 design storms to the TUFLOW model (direct rainfall and hydrologic modelling), care needs to be taken to ensure that consistency in the applied inputs (rainfall depths and temporal patterns etc) is maintained. This is discussed further in Section 5.3.

The downstream boundaries are a mixture of water level boundaries (type HT) and normal depth boundaries (type HQ). HT represents the ocean levels with all HT boundaries applying a consistent fixed ocean water level for design events. The HQ boundaries represent spillage into neighbouring Bohle basin. All downstream boundaries are within the 2D domain except for one within the 1D domain (Garbutt) which is specified as an HQ boundary and represents piped flow which enters the Bohle stormwater network.

4.3.5 Output Settings

No map velocity or depth cutoff criteria have been specified for the results within the tcf. By default TUFLOW sets the 'Map Cutoff SGS' to 'Exact' meaning that 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 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 users should be aware that this setting is applied.

The AECOM report refers to additional post processing of results undertaken as part of the flood study to meet the requirements of TCC[3]. BMT has not been supplied these processed results and so cannot comment on them further.

4.4 Model Calibration

Calibration was undertaken to the events of January/February 2019, February 2018 and March 2012.

The 2019 event was the largest modelled event and the model calibration demonstrates that a reasonable calibration has been achieved. Overall the model generally replicates well the rise and fall of the event and the comparison to debris marks show that the peak flood level has been matched reasonably well.

AECOM has demonstrated that effort has been invested in analysing the debris marks and identifying ones that are potentially erroneous.

[3] Post processing is stated as being all maps were filtered to depths above 0.1m except where velocities exceed 0.8m/s

For the 2018 event there is a slight general tendency to underpredict peak gauge levels and for the 2012 event there is a reasonable match to gauge levels, ignoring the obvious errors in some of the gauge records.

In conclusion BMT is satisfied that a suitable model calibration has been achieved for the purposes of the flood study assessment.

4.5 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 Ross River model
4.2	Results for the 1% AEP, 120h duration event could not be replicated exactly using the specified build of TUFLOW.	AECOM to check and provide explanation.
4.2	It would be beneficial to state the source of the levee elevation data within in the model files.	Add note to tgc model file stating source of topographic levee data
4.3	The tidal waterway of the Ross River has a Manning's n value of 0.055 which is unusually high for a tidal system	None, given the calibration is reasonable.
4.4	John McIntyre Bridge on Southern Port Road is a major bridge over the Ross River and is not included in the model	Its inclusion is not expected to change results but should be included for completeness given that it is a major bridge.
4.5	Some culverts not included on minor drainage channels eg within the barracks	Include short statement on the limitations of the assessment
4.6	A default map cutoff depth is applied which will differ to that requested by TCC (of 0.1m).	Cutoff depth applied appears reasonable but TCC to review against requirements.

5 Determination of Design Floods

5.1 Overview

The approach to design flood estimation applied by AECOM uses approaches contained within the ARR2019 guideline. Two approaches to design flood estimation were undertaken as follows:

- Flood Frequency Analysis (FFA) on the RRD outflow
- Design event simulation using the calibrated models.

The FFA was used to inform the selection of appropriate model simulations to derive the RRD outflows.

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 FFA

The FFA was performed by HARC on behalf of AECOM for the RRD outflows and is documented within Appendix C of the AECOM report. HARC notes that the previous FFA (HARC, 2017) was based on daily flow records of a 41 year period extending to 2015. The FFA was updated by extending the RRD outflow record as follows:

- Incorporating records up to 2020, noting that this includes the largest event on record in 2019.
- Analysing daily flow records at Gleesons Weir from 1916 to 1960 but using these as a surrogate for RRD inflows. These RRD inflow estimates were then converted to RRD outflow estimates, had the dam been in place during that time with the same operating rules as present.

HARC has also undertaken additional analysis on the rarity of the 2019 event and used this to inform further adjustment for bias in the FFA results. This was done by effectively adjusting the plotting position[4] of the 2019 event on the basis that the event was of greater rarity than its plotting position suggests.

It is noted that the resulting 1% AEP flood frequency estimate at the RRD outflow determined in this study is 863m^3/s which compares to a previous estimate (HARC, 2017) of 944m^3/s. This is despite the largest event on record occurring within the period between the two estimates. BMT assumes that this is due to the longer period of recorded now being included by incorporating surrogate dam outflows based on Gleesons Weir flows. It is recommended that the flood study report is updated to add some short commentary on this finding. Overall, the updated 1% AEP modelled flow is notably larger than the previous flood study estimate of 745m^3/s (TCC, 2013).

5.3 Design Event Simulation

As discussed in Section 2, design event simulation has been performed in two parts;

- RRD, upper catchment dominated events (long critical durations) with no downstream catchment flows

[4] In summary, this was achieved by removing the 2019 event from the annual maximum series and incorporating its recorded peak outflow of 1888m^3/s as a censored threshold.

- Local, downstream catchment dominated events (short critical durations) with only minor discharges from RRD.

The hydrologic assessment has distinctly separate analyses and ARR2019 assumptions for the upper and lower catchments. The hydraulic model is then used to simulate and combine the results from both approaches. The ARR2019 assumptions employed as discussed below for the upper and lower models respectively.

5.3.1 Upper Model

The upper model analysis is concerned with generating design outflows from the RRD. As such all ARR2019 parameters are selected based on the catchment area to the RRD (757km^2). This includes derivation of ARFs and use of areal temporal rainfall patterns.

The design rainfall losses are set to 0mm for initial loss and 0mm/hour for continuing loss for all events of the 1% AEP and rarer. This is considered conservative, given that the ARR2019 recommendation for the PMP is to apply 1mm/h continuing loss. Ultimately as the events are selected based on FFA results, the adopted losses have minimal bearing on the outcomes and so this is not a concern.

5.3.2 Lower Model

The areal reduction factor (ARF) is set to a value of 1 for the lower Ross River catchment models meaning that no areal reduction is applied to the design point rainfall estimates. This will result in a conservative estimate of design rainfall across the catchment but not significantly so given that the catchments under consideration are relatively small. It also negates the complexities of allocating different ARFs to different parts of the catchment.

Point rainfall patterns have been applied on the basis of each separate model having a contributing catchment area less than 75km^2. This is considered acceptable given that the catchments represented by the models either drain with their own outlet to the ocean or combine with the Ross River near the ocean.

The same ARF assumption and point rainfall patterns have been applied to the area modelled as direct rainfall so consistency is maintained.

Table 5.1 below summaries the design 1% AEP rainfall losses reported for each model within the supplied extracts within Appendix B of the AECOM report. When querying the supplied XP-RAFTS model files, BMT notes that all models use a global pervious initial loss (storm) of 60mm and a continuing loss of 2.0mm/h. This is inconsistent with the reporting and it is recommended that the modelled values are included in the report.

It is noted that the direct pervious rainfall initial losses applied within the TUFLOW model are specified as being 70mm in Table 7 of the AECOM report. However checks on the TUFLOW model files for the 1% AEP event indicate that a value of 60mm was used which is consistent with the hydrologic model. This should also be updated in the report.

Table 5.1 Design Rainfall Losses (1% AEP event) for each Hydrologic Model

Model	Initial Loss (mm)	Continuing Loss (mm/h)
Mundy Creek	50	2.5
North Ward	40	2.5

Model	Initial Loss (mm)	Continuing Loss (mm/h)
Ross Creek	70	2.5
Stuart Creek	60	2.0
Sandfly Creek	60	2.0

Table 5.2 lists the pre burst depths extracted by BMT from the ARR datahub website. These correspond to the values applied by AECOM to the storm initial loss to obtain the burst initial loss. For the majority of durations the burst initial loss (derived by storm initial loss minus pre burst depth) becomes zero.

Table 5.2 1% AEP Median Pre Burst Depths

Duration (min)	Pre Burst Depth (mm)
60	20.1
90	51
120	60.3
180	81
360	100.4
720	75.9
1080	75.8
1440	54.9

Extracted for lat -19.27, long 146.834

Overall, the application of design event parameters is considered appropriate for the purposes of the flood study.

The downstream boundary is specified as a constant level set at MHWS (1.254mAHD) for all design events. This is in accordance with the TCC Guideline.

5.3.3 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 modelled 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.

There are numerous separate hydrologic models used in the assessment and the event selection process is conducted without consideration for connectivity between the models. Whilst this does introduce some relatively minor limitations, overall the approach is considered satisfactory due to:

- The RRD has a significant effect on catchment behaviour and causes a large disconnect in critical durations. The critical duration of flow out of the dam (identified as being 120 hours) is significantly longer than durations critical for local downstream catchment runoff. The critical durations are considered to be sufficiently spaced so that modelling of the upper catchment runoff through the hydraulic model with no downstream catchment runoff is unlikely to make any material difference to the outcomes of the assessment.

- The separate lower Ross River catchment models either discharge to the ocean separately or join in the very lower reaches of the creek where ocean conditions will dominate eg Stuart Creek and Ross River
- The hydraulic model will still account for linkages (spillover) between the catchments at higher flows (albeit this won't be accounted for in the hydrologic event selection process).

The upper Ross River model event selection is effectively conducted at a point location, being the downstream limit of the model at the RRD. This is appropriate given that the area of interest is downstream of the dam. Rather than select representative average ensemble members, for each modelled AEP/Duration, the approach taken has been to select an ensemble member (temporal pattern) which results in a peak flow closest to the flood frequency estimate. For the 1% AEP event a peak modelled outflow of 827m^3/s was selected compared to the FFA estimate of 863m^3/s. The associated reporting does not detail where this ensemble member sits within the ensemble i.e. towards the upper or lower end of flow estimates, however given that the 1% AEP FFA and modelled flow estimates are within 5% of each other this provides increased confidence in the assessment.

The event selection process is conducted separately for catchments downstream of the RRD. The hydrologic model is used to select representative average ensemble members based on peak flow. This was done for each subcatchment that falls within the hydraulic model domain. A critical duration assessment was then performed on each subcatchment using the representative ensemble members. The results were mapped in the form of a critical duration map with each subcatchment allocated a critical duration. The catchment area falling within each critical duration was then analysed to see which representative temporal pattern/s for each duration is dominant. A subset of dominant temporal patterns (typically one or two per duration) were selected for hydraulic modelling. The selected temporal patterns are listed in Table 8 of the AECOM report. Each modelled AEP is comprised of a subset of ten component events for the shorter critical durations.

AECOM report that a validation check was performed on the 1% AEP using a coarse scale hydraulic model by simulating each ensemble (10 events) for each duration. A hydraulic critical duration map was produced (Figure D22). This can then be compared to Figure D5 which shows the hydrologic critical duration mapping for the 1% AEP event. No commentary on the comparison is provided by AECOM other than providing the maps. Based on a visual comparison by BMT, the results are generally as would be expected with longer durations being critical at downstream locations. There are differences between the hydrologic and hydraulic assessments, but this would generally be expected given that the hydraulic model will better capture floodplain attenuation and account for tailwater. To improve the comparison it is recommended that the final 1% AEP component events for the lower ross river are presented in the form of a critical duration map at the same scale to that shown in Figure D22. This would allow a hydraulic model comparison of an event selection process conducted in the hydrologic and hydraulic models.

In conclusion, it is BMTs opinion that the event selection process is a pragmatic one undertaken in accordance with the principles of ARR2019 and which provides for transparency of approach. The subsets of events for each modelled AEP are not excessive in number and contain a sufficient number of durations to adequately cover the catchment sizes of interest.

5.3.4 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.

Typically the purpose of the assessment is to gain an understanding of the sensitivity of peak flood levels to the tailwater assumption for design event modelling. It provides an upper (fully dependent) and lower (fully independent) bound on the range of flood levels which could be expected within those parts of the floodplain which are potentially subject to flooding caused by both catchment runoff events and ocean storm surge events. It also delineates a 'joint probability zone 'JPZ' within which resulting flood levels may be sensitive to the choice of downstream boundary condition.

The AECOM study follows the approach specified by TCC and does not incorporate any storm surge component within the downstream boundary. As such the flood study flood levels will match the riverine component of the fully independent surface i.e will match the lower bound.

The sensitivity test therefore essentially shows by how much, and over which areas, the modelled peak flood levels could increase if a storm surge component was incorporated into the flood modelling assessment.

In conclusion AECOM notes that the maximum flood level within the JPZ under an upper bound (dependent) scenario is 3.15mAHD and that this is lower then TCC's defined storm tide level[5]. As such there is no additional value in refining the tailwater assumptions further. BMT is in agreement with this finding.

Under a future climate scenario the peak flood levels in the JPZ increase beyond TCC's defined storm tide levels and AECOM concludes that the increases warrant further investigation beyond the simplified pre-screening approach. BMT generally agrees with this statement and also notes that the use of a MHWS tailwater (albeit inclusive of SLR) will match the lower bound (independent) range of flood levels. Another option that could be explored is to incorporate a time varying tailwater boundary that incorporates an element of storm surge but with an AEP more frequent than that of the flood under consideration. This will result in design flood levels between the upper and lower bounds which may be appropriate.

Overall BMT has identified no issues with the JPZ sensitivity undertaken by AECOM.

Structure Blockage

A blockage assessment has been undertaken which is in accordance with ARR2019. This includes an assessment of the debris size (L_{10}) for different land use types. The assessment is undertaken for both

[5] BMT understands that TCC's defined storm tide level projections for sea level rise to 2100.

the 50% and the 1% AEP events. In BMT's opinion, the blockage assessment is considered thorough (for a flood study) and blockage values are sensible and have been derived appropriately.

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.

Overall, AECOM has demonstrated that model results only show minor sensitivity to structure blockage.

5.3.5 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), and classified hazard in accordance with the TCC flood hazard overlay. The results are presented across 24 regions of the model domain. Results are also presented as long sections of peak water level and tabulated peak levels at nominated locations.

A minor comment is that the critical duration mapping within volume 2 labels the maps with velocity output. BMT assumes this should be 'Critical Duration'.

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 by suburb
- Commentary on what AEP inundates community buildings and infrastructure
- AEPs and associated flood depths affecting major roads.

5.4 Comparisons to Previous Assessments

The Ross River Flood Study replaces model output previously developed across seven component sub-catchments (Ross Creek, Gordon Creek, Douglas-Annandale, North Ward, Captains Creek, Stuart Creek and Ross River).

Section 4.3 (Figure 51) of the AECOM report presents a comparison of the updated flood study results versus those of the previous studies for the 1% AEP peak flood level. AECOM provide some commentary on the changes in flood level.

Overall BMT agree with the AECOM commentary and that the increases in peak level along the Ross River are largely due to the increase in 1% AEP peak design outflow from the RRD.

Other differences will be subject to numerous factors such as use of ARR2019, more recent LiDAR and bathymetry data, better model resolution and the ability to model the study area within a single model as opposed to multiple models. It is not possible to attribute the differences to component factors without further investigations. As an overall comment, the updated model represents a significant improvement over the previous and should be viewed as representing current best practice.

5.5 Summary of Design Flood Estimation Recommendations

Table 5.3 Design Flood Estimation Summary

ID	BMT Observation	BMT Recommendation
5.1	The updated RRD FFA results are lower than those of (HARC, 2017) despite inclusion of the 2019 event in the updated study (largest event on record).	Update flood study report (HARC report) to provide short commentary on this outcome
5.2	A continuing rainfall loss of 0mm/h for the 1% AEP and rarer is low considering ARR2019 recommends a CL of 1mm/h for the PMF event.	Observation only. As event selection is informed by FFA then use of different losses will not affect the assessment to any notable degree.
5.3	Initial and continuing design rainfall losses quoted in report (which refers to Appendix B) differ from those applied in the XP-RAFTS models	Update report to reflect what is in the models
5.4	A sensitivity check on the event selection process has been undertaken by comparing the critical durations determined hydrologically with those determined hydraulically for the 1% AEP event using a coarser scale model. It is difficult to compare the two approaches and no commentary is provided on the differences.	The check could be improved by comparing the hydraulicly determined critical durations with the hydrologic determined durations following simulation in the hydraulic model.
5.5	Critical duration mapping presented within Volume 2 of the AECOM report labels the maps with ‘velocity’.	Replace ‘Velocity’ with ‘Critical Duration’.

6 Other Considerations

6.1 Post Processing of Model Results

The model results provided to BMT are the component raw outputs from the TUFLOW model. For example, the 1% AEP event contains ten peak water surfaces for the shorter durations (lower catchment dominated events) and a further one event for the long duration (120h) RRD outflow dominated event.

Based on AECOM reporting, these 11 flood surfaces have then been enveloped by taking the maximum peak water level from the component surfaces. This is appropriate. AECOM reports that post processing was also undertaken in accordance with TCCs requirements whereby results were filtered to depths above 0.1m except where velocities exceed 0.8m/s. BMT does not have these grids to verify the output but agrees that this process is in accordance with TCCs request. One thing to note is that the inclusion of the ‘Map Cutoff SGS == ‘Exact’ command (see Section 4.3), may mean that for some cells containing a large elevation range the cut off depth could be greater than 0.1m. Overall this is not expected to have any notable bearing on the outcomes.

6.2 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.

6.3 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 modelling contract undertaken by AECOM for the Ross River Flood Study Update 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. The hydraulic model developed in the assessment represents significant improvements over previous models.

Observations and recommendations have been made by BMT on key aspects of the study. No significant issues were identified by BMT but a number of minor issues have been noted, the majority of which relate to requests for clarifications within the report.

8 References

AECOM (2021) Base-line Flooding Assessment – Ross River Flood Study – Volume 1 and 2. Prepared for Townsville City Council, October 2021

AECOM (2019) Review of Hydrological Methods for the Townsville Region: Phase 4 – AR&R 2019 Hydrologic Model Updates. Prepared for Townsville City Council, September 2019.

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

DERM (2011) Queensland Coastal Plan.

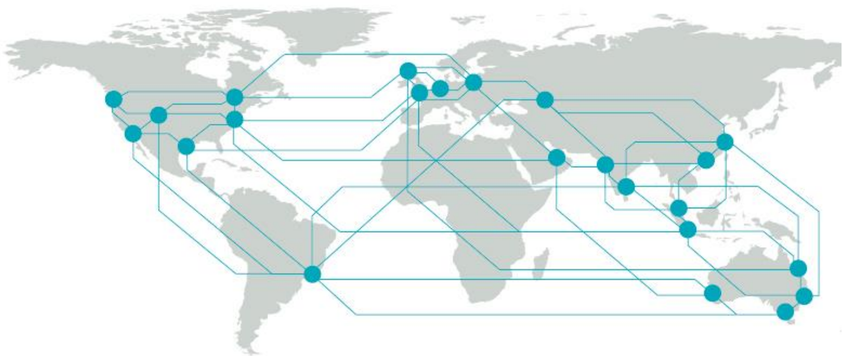
HARC (2018) Review of Hydrological Methods for the Townsville Region: Phase 3 – Catchment Simulations for Test Catchments. Prepared for Townsville City Council, September 2019.

HARC (2021) Ross River Dam Hydrology Update Final v1. Prepared for AECOM, April 2021.

Queensland Coastal Plan (DERM, 2011)

TCC (Undated) Townsville Recalibrated Flood Modelling and Mapping – The Ross River and its Surrounding Areas', Particulars of Consultancy Services (DRAFT) Phase 1.

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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