Peer Review of Black River Flood Study Hydraulic Modelling and Mapping

Reference: R.A10416.003.00_Black_River_Review.docx
Date: May 2021
Confidential

Document Control Sheet

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Synopsis:	**Peer Review of Black River flood modelling and mapping (inclusive of Althaus Creek and Bluewater Creek) as part of Townsville City Council's Flood Modelling and Mapping Project.**	

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	28th May 2021	CLB		BR	

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
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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 four separate contracts with each contract pertaining to a hydrological catchment (or group of catchments). These four areas are modelled as separate domains by different consultants:

- Bohle River catchment
- Black River, Althaus and Bluewater Creeks
- Ross River and Surrounds
- Alligator Creek and Whites Creek.

This peer review report documents the review findings for the modelling contract undertaken for the **Black River, Althaus and Bluewater Creek** catchments by AECOM.

1.2 Supplied Data

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

- Base-line Flooding Assessment: Black River Flood Study Volumes 1 and 2 (AECOM, 2021)
- Request for Quotation: Flood Model Updates for ARR 2016: Hydrologic Models and Black River Hydraulic Model (TCC, October 2019)
- Variations.pdf which documents amendments to the project scope
- Townsville Recalibrated Flood Modelling and Mapping Naming Convention Report (TCC, March 2020)
- TUFLOW hydraulic model:
  - All model input files;
  - A subset of peak result grids:
    - Calibration events;
    - Design events (processed for critical duration envelope);

    - Sensitivity scenario events (including afflux);
    - Critical duration analysis grids;
- Previous study result grids;
- XP-RAFTS hydrologic model;
    - All model files; and
    - GIS Catchment layer and ellipses for PMF.

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 ARR1987 and the MIKE FLOOD modelling tool in 10m grid resolution); 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.

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

A single hydraulic model has been developed using TUFLOW HPC software for the Black River basin, including the Bluewater Creek and Althaus Creek catchments. This model is the focus of this peer review.

Inflows to the hydraulic model are generated from hydrologic models and from rainfall applied directly to the hydraulic model domain. The hydrologic models were developed under a separate commission[1] and are outside the scope of this peer review except insofar as to how the inflows have been applied in the hydraulic model. It is understood the hydrology is based on the Australian Rainfall and Runoff 2019 guideline (ARR2019).

The hydraulic model utilises a 5m model grid and was calibrated to available data for the January/February 2019 event and validated to the January 1998 flood. The model was 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.

The remainder of this report sets out the key findings from our peer review of the hydraulic modelling covering both the technical setup and quality of the models as well as the overall modelling approach. It is recognised that much of the modelling approach is driven by the hydrologic assessment. Peer review commentary on the modelling approach is therefore limited to the overall suitability and defensibility of its implementation in the hydraulic model.

[1] Review of Hydrological Methods for the Townsville Region' project (AECOM, 2020)

3 Hydrologic Assessment

As described in Section 2, the development of the hydrologic model used in the assessment (AECOM, 2020) was undertaken separately to the hydraulic modelling prepared by AECOM and is separate to the contract which is subject to this peer review. AECOM utilised their previously developed hydrologic models for each of Bluewater Creek, Althaus Creek and Black River, incorporating minor updates and resimulating to generate inputs for the hydraulic model. AECOM's reporting on the hydrologic assessment only makes brief referral back to their previous report, with no specific documentation such as parameters used (particularly for direct rainfall application) included in the current reporting. Hydrologic assessment reporting is limited to an overview of the critical temporal pattern selection method, with outcomes reported but insufficient detail on the process reported. As such it is recommended that an appendix is included that documents the selection method for events taken through to hydraulic modelling in more detail. Further detail should also be provided on the ARR2019 parameters, rainfall inputs and loss assumptions used in the direct rainfall modelling, and how these correspond with the hydrologic modelling parameters.

A single IFD location appears to have been used to generate rainfall for the 2d_rf direct rainfall inflow polygon (see Item 4.2.6.4). No documentation is provided on this. It is unclear if it differs to the IFDs used in the hydrologic models, and if other ARR parameters are consistent with the hydrologic models. It is recommended that these details are added to the report, and the outcomes of this inflow approach are cross checked against the hydrologic model results.

4 Hydraulic Assessment

The following sections provide commentary and recommendations following peer review of the TUFLOW hydraulic model configuration and modelling approach.

4.1 General considerations

Table 4-1 Hydraulic Model – General considerations

ID	BMT Observation	BMT Recommendation
4.1.1.1	**Executable version:** Simulations were reported to have been undertaken with TUFLOW Build 2020-01-AB. This was the latest executable build available at the time the project was being completed. This cannot be confirmed as no TUFLOW simulation log files, or batchfiles, were provided.	Appropriate.
4.1.1.2	**Executable Precision**: No TUFLOW simulation log files, or batchfiles, were provided to easily confirm the precision executable used. However, HPC simulations initiated with the double precision executable (iDP) will cause an error by default, and the TCF did not contain the command to suppress this. Hence it appears simulations were undertaken with the single precision (iSP) version of the TUFLOW Build. This is appropriate for use with direct rainfall modelling when simulating with the HPC Solver.	Appropriate.
4.1.1.3	**Control file structure:** A single TCF has been configured to contain all relevant scenarios and events. The configuration of logic blocks and the use of automatic variables has been reviewed, and is confirmed to be appropriately defined and utilised, effectively organising model inputs and outputs. This is considered good practice, and is recommended.	Appropriate
4.1.1.4	**Events simulated:** Design, sensitivity and calibration events modelled and mapped as specified in the study RFQ and variations.	Appropriate.
4.1.1.5	**Critical duration - Approach:**	The simplified approach appears appropriate based on the limited

ID	BMT Observation	BMT Recommendation
	It is understood that the hydrologic model has been used to select a single representative temporal pattern per duration for application to the entire model, based on an assessment of a number of separate locations. A second temporal pattern per duration (for those 360m and above) with an alternative shape was also simulated and enveloped for final results. Selection of temporal patterns appears to have been made based entirely on hydrologic results, and no assessment of critical storms relative to peak flood levels throughout the study area was undertaken. However it is noted that all durations with their selected temporal patterns have been included in the enveloped final results. It is BMTs understanding that the ARR approach for selection of a mean temporal pattern relates to a specific location of interest, as also identified by AECOM. For a flood study such as this, the entire area could be considered of interest. AECOM has reported that "*the points of interest were identified as sub-catchments with the most critical model inflows from each of the three catchments"* and that for shorter storm durations (less than 4.5h) locations used were representative of more developed and upper catchment reaches. It is not clear from reporting where and how many points of interest were assessed and a map showing these locations would be beneficial. It is not clear on what basis a "best match" temporal pattern was selected that applied to these locations. An example demonstrating the process would assist in this regard. Reliance is placed on the hydrologic model to select critical events. It is noted by AECOM that the hydrologic and hydraulic flows were within 10% of each other for the 10% AEP and 1% AEP events respectively which provides confidence in the results, given that the event selection has not been performed in the hydraulic model. All standard durations (with the associated one or two selected temporal patterns) have been hydraulically modelled per event, and the results enveloped for mapping of peak results. A single critical duration map for the 1% AEP event is provided in reporting, which shows the 270m, 360m (x2 temporal patterns), 540m are critical in the majority of the study area (watercourses and floodplains), with the 90m critical in the most upstream areas. Additional critical duration maps could be provided for the other events. The legend of these maps could be updated to also show the temporal pattern ID, particularly where the same duration was run for two temporal patterns.	documentation available. It is recommended to include temporal pattern hydrograph plots and box plots to make the selection clearer, and demonstrate the spread of results. Further justification should be included to demonstrate the appropriateness of the selected "best match" temporal pattern for the points of interest. To verify that the hydrologic modelled flows and hydraulic modelled flows are in general agreement (and could be expected that a critical temporal pattern assessment would give similar results in the hydrologic and hydraulic models), it is recommended that peak flows from the hydraulic and hydrologic models are compared at the nominated locations. Add critical duration maps for events other than the 1% AEP, and update legends of these maps to indicate the temporal pattern associated with each duration.

ID	BMT Observation	BMT Recommendation
4.1.1.6	**Naming convention - TCF and raw outputs:** TCC's Naming Convention document was reviewed and compared to the model TCF filename (and hence raw results output filename) configuration. Identifiers specified by TCC were generally appropriately assigned by AECOM, however minor differences in the configuration of model filenames were identified: • Enveloped results data types did not appear to be given the identifiers specified nor the GIS result type (e.g. G 'grid'), however only provided peak level results were available to confirm; • A 2 character Run ID was included, instead of 3 as specified. • The format of the TCF filename, and hence the raw output results, has been configured with a hyphen between the ""EEE"" event and ""FFF"" ""GGGG"" duration/temporal pattern identifiers, which was not specified. However, it is noted that in post-processing and enveloping results of critical storms for each design event, the ""FFF""""GGGG"" identifier is necessarily removed anyway. This may only be significant should the format differ from other consultant's studies, and TCC wish to ensure consistency.	Identifiers were generally assigned appropriately and are clear, and filenaming does not impact results. However, it is expected that TCC will require consistency across other studies by other consultants. TCC to review if the filenaming of models and results is acceptable, and appropriately consistent with other consultants' studies as required.
4.1.1.7	**Naming convention - post-processed outputs:** It is good practice for post-processed results filenames to reflect the raw results filenames as much as practically possible (with consideration, for example, to appropriate naming when enveloping results) for clarity on simulation source. The post-processed results' filenames were confirmed to be consistent with the TCF and raw output filename configuration (after accounting for enveloping results of critical storms for each design event, e.g. the "FFF""GGGG" identifier is necessarily removed).	If changes are deemed to be required to model file names (see above comment), then post-processed results' filenames will need to be equivalently updated.
4.1.1.8	**Naming Convention – inputs:** Filename structure for model inputs has been assigned the "AAA" model identifier as specified in TCC's Naming Convention document, but not the "CDDD" identifiers. Underscores have also been used instead of hyphens. Inputs have not been assigned a model development stage ID which is considered best practice, but may be considered unnecessary for a cleaned and finalised model. Some filenames could have been given the "ZZZ" scenario identifier as appropriate, e.g. the blocked culverts layer for the sensitivity assessment. Hydrology output files have been appropriately renamed for application to TULFOW with the equivalent identifiers in the filenames that allow effective use of event and scenario logic.	There are minor differences, however these do not affect the outcome of results, and are unlikely to cause issues if there is any inconsistency in approach with other consultants' studies.

ID	BMT Observation	BMT Recommendation
4.1.1.9	**Naming Convention - Model directory structure:** The Naming Convention document does not comprehensively describe the folder structure required to categorise all outputs. The hydraulic model folder structure conforms with that recommended by TUFLOW, and accepted as best practice. The model directory structure adopted for GIS hydraulic model outputs is sensible and generally conforms with the information in the Naming Convention document.	Appropriate

4.2 Model Structure

4.2.1 TUFLOW Control File (TCF)

Table 4-2 Hydraulic Model – TUFLOW Control File

ID	BMT Observation	BMT Recommendation
4.2.1.1	**Solution Scheme:** Simulations were configured with the TUFLOW HPC Solver. GPU hardware has been appropriately set for the most efficient application of the HPC Solver.	Appropriate.
4.2.1.2	**Projection**: The model is correctly configured in projection GDA94 MGA Zone 55.	Appropriate.
4.2.1.3	**Sub-grid Sampling:** SGS sampling is utilised, a recent addition to TUFLOW's functionality.	Appropriate.
4.2.1.4	**BC Event Source**: BC Event Source definitions have been configured to utilise automatic variables for the relevant scenarios/events – a clean and efficient configuration.	Appropriate.
4.2.1.5	**Checkfiles**: The output of checkfiles are configured for calibration events only. As checkfiles can be easily reproduced later if required, this is reasonable. However, checkfiles should be considered a useful quality assurance tool and output where reasonable.	Additional organisational functionality (scenario/event logic and check file include/exclude commands) could be added in future to logically output checkfiles for select situations. For example, to reduce potential repetition of some checkfiles that would not change with design even simulations (e.g. geometry

ID	BMT Observation	BMT Recommendation
		checkfiles) whilst retain boundary checkfiles, or to exclude the large checkfiles that may be less likely to be inspected (uvpt, zpt).
4.2.1.6	**Cell wet dry depth**: A reduced cell wet dry depth does not appear to have been set, and log files are not available to confirm. It is considered best practice to reduce the cell wet dry depth to 0.0002 m for direct rainfall modelling, even when using the HPC Solver. This reduced value is also recommended when steep flow occurs.	Test the sensitivity of model results to applying a reduced cell wet dry depth of 0.0002 m, and consider implications for study results.
4.2.1.7	**Start Time**: Not set but confirmed in TLFs that it has defaulted to 0 hours. The JAN98 calibration event forces a 25 hour start time (via the TEF).	Appropriate.
4.2.1.8	**Timestep:** Not set, but defaults to 1s. This is only used for the initial timestep - HPC uses adaptive timestepping thereafter by default.	Appropriate.
4.2.1.9	**Map Output Types**: • Map output data types for maximum gridded datasets for peak depth, level and velocity have been specified consistent with the study RFQ. • ZAEM1 hazard was additionally also output and mapped. • A flood hazard overlay was mapped as per TCC's flood hazard criteria, following post-processing from TUFLOW's Z4 output for the 1% AEP event and the PMF extent. • Minimum timestep (dt) has been additionally specified for calibration events, but not for design events. This is a valuable tool for assessing HPC model stability and is recommended to be included.	Appropriate. It is recommended that the dt output grid is retained for all simulations.
4.2.1.10	**Map Output Format**: Map output format does not appear to have been specified in the study RFQ. XMDF and FLT formats have been selected for temporal and maximum gridded results, respectively. These are standard and considered acceptable.	Appropriate.
4.2.1.11	**Map Output Intervals**: Temporal output is appropriately turned off for gridded datasets - only maximums are output. It is also turned off for XMDF map output types by default, however the TEF sets reasonable duration dependant intervals for temporal XMDF data for design events.	Appropriate.

ID	BMT Observation	BMT Recommendation
4.2.1.12	**SGS Map Output Controls:** Mapping controls necessary for SGS enabled models have been appropriately set, including for Map Cutoff SGS and SGS Map Extent Trim, which ensure that all results are trimmed to match the extents based on the depth-based map filtering.	Appropriate
4.2.1.13	**Plot Outputs:** A limited number of plot output (2d_po) reporting lines (flow) and points (water level) have been included in the model. Plot outputs are specified at the two gauged sites on Bluewater Creek and Black River. The orientation and location are reasonable. For the Black River gauge, the 2d_po flow lines appears of a sufficient length to capture the entire flow width up to the 0.05% AEP. For the Bluewater Creek gauge, the length appears sufficient up to the 0.2% event. 2d_po lines do not appropriately capture flow rates for the PMF. Other reporting locations are generally reasonable. The 'AlthausCk' 2d_po flow line is not orientated perpendicular to flow, and results for it would be unreliable.	Generally appropriate. The suitability of the use of flow rates from 2d_po lines (insufficient length to capture full flowpaths) should be reviewed if data is required for the larger events. The inclusion of additional reporting 2d_po lines and points could be considered for future simulations, to ensure data is available at more points of interest, and to aid in model review and quality assurance.
4.2.1.14	**Initial Water Levels**: The IWL is set to "AUTO" which ensures that it matches in the 1D and 2D domains to the relevant scenario-dependant static tidal downstream boundary. The boundary levels adopted, and hence IWL applied, appears appropriate in relation to the downstream topography and bathymetry, with the exception of a section of the Black River mouth (see Item 4.2.3.6).	Appropriate.
4.2.1.15	**XFs**: XF files are used by default.	Appropriate.
4.2.1.16	**Map Cutoff Depth**: Direct rainfall modelling requires filtering of results to remove shallow depths to produce a more usable product. The automatic Map Output Cutoff Depth command has been used to directly filter results prior to output by TUFLOW to depths greater than 0.1m. The study RFQ had identified filtering the direct rainfall results through post-processing by applying Council's own depth and velocity dependent filtering criteria, which excludes flooding results in areas where the depth of flow is less than 100 mm unless the velocity is greater than 0.8 m/s. This has not been applied to the raw results. It is assumed this was agreed with Council.	Appropriate. Confirm filtering process was agreed with Council.
4.2.1.17	**Maximum Velocity Cutoff Depth**: set to zero to track the maximum velocity irrespective of the velocity at the peak water level. This can potentially result in mapping showing high velocities for shallow depths and would be a conservative approach.	Appropriate.

4.2.2 TUFLOW Event File (TEF)

Table 4-3 Hydraulic Model – TUFLOW Event File

ID	BMT Observation	BMT Recommendation
4.2.2.1	**Structure**: Scenario blocks defined for End Times and Map Output Interval, set up correctly and neatly. BC Event Source set with automatic variables directly in the TCF.	Appropriate.
4.2.2.2	**XMDF Map Output Interval**: Sets reasonable duration dependant intervals for temporal XMDF data for design events, overwriting the default 'off' command in TCF.	Appropriate
4.2.2.3	**End Time**: Scenario dependent simulation end times have been set for the design durations and for calibration. The same end time is set irrelevant of temporal patterns (TPs) for a given duration. The tmax_h results grids were inspected for calibration events and for all available durations for a frequent (50%) and rare (0.5%) design event. Tmax_h results were not supplied for 1080m and 1440m durations. In both design events checked, the 60m, 90m, 120m and 180m durations showed areas of the main river channels and some downstream areas where the maximum water level was at the end of simulation, potentially indicating the water levels had not yet peaked. Otherwise, the only areas that appeared to be "peaking" at the end of simulation, appeared to be where water had pooled and was unable to escape, maintaining a constant water level until simulation completion. Plot output CSVs were not available to provide any further insight (and it is noted that no suitable plot output reporting locations for checking this have been included in the model). It is noted that reporting documents the Jan 2019 calibration event as being simulated for 6.25 days to capture the recorded peak, however the simulation is configured to 120 hours (5 days), and this appeared sufficient. .	AECOM to ensure that end times have been set to capture peak flows for different event/duration combinations, as some shorter durations do not appear to have peaked in the downstream areas of the model. Configuration structure is appropriate. Updating reporting for January 2019 to reflect simulation length.

4.2.3 TUFLOW Geometry File (TGC)

Table 4-4 Hydraulic Model – TUFLOW Geometry File

ID	BMT Observation	BMT Recommendation
4.2.3.1	**Code and orientation**: The domain extent and orientation are generally reasonable in relation to active code area, however there is a large redundant area outside of the active code extent where the domain extents could be trimmed. This may have implications for memory requirements, but does not affect results. The active code extent is appropriate. The entire subcatchments are included in the active code extent where direct rainfall is applied. Glasswalling of water against the code boundary has generally been avoided, however there are some minor areas at the most upstream extent of the 2d_rf direct rainfall polygon, where it sits flush with the code boundary and does not precisely align with the top of catchment. This is more noticeable in the larger events. There is some glasswalling in the PMF event along the code extents where flow drains to the neighbouring catchments via 2d_bc HQ boundaries, which could be remedied by extending some of the boundaries to cover the full flowpath. There is some glasswalling where flow backs up in larger events at catchments C5, H2, B6-a-1 in larger events. These occurrences are not expected to significantly impact results.	Generally appropriate. Some minor areas of glass walling could be reduced by adjusting the code extent or boundary lengths, should the models be otherwise required to be rerun. These occurrences are not expected to significantly impact results overall.
4.2.3.2	**Cell Size**: The model has a 5m grid resolution which is considered appropriate and fit-for-purpose.	Appropriate.
4.2.3.3	**SGS Sample Distance**: A 1m SGS sampling resolution has been set. This is appropriate and will capture additional available detail in the base 1m topographic dataset.	Appropriate.
4.2.3.4	**Hydraulic Roughness:** Three GIS delineation layers have been defined. These were confirmed to be appropriately layered. Gaps in the delineation have been infilled with Mat ID 526 with a Mannings of 0.043. The DEM_ M (land use check file) was inspected and this default value does not appear to have been assigned inappropriately – i.e. there were not any significant gaps in the materials delineations. Inspection of the DEM_M and input files confirmed that delineation of hydraulic roughness categories appears appropriate, and suitable Mat IDs have been appropriately assigned to those delineated areas. Some areas have a relatively coarse delineation of categories (i.e. lumped definitions based	Delineations of the Mat ID are considered appropriate for catchment scale. Delineation of hydraulic roughness categories could be further refined if used for localised assessments.

ID	BMT Observation	BMT Recommendation
	on broad land use categories), however this is considered suitable for study objectives. It is noted that this layer also defines the spatial distribution of material-dependent losses via the TMF (see Section 4.2.4 for further discussion), applied for 2d_rf direct rainfall areas.	
4.2.3.5	**Base Topography**: Two base LiDAR topographic datasets are used in the model with the later 2019 dataset being clipped and applied only where it represented new development compared to the 2016 dataset, due to quality issues identified by TCC. This data has been layered appropriately. The clipped extents of the 2019 LiDAR included in the model was confirmed to merge well with the underlying 2016 LiDAR. The LiDAR also has poor triangulation across the channels in the downstream area. However, considering the tidal influence in these areas at the time of capture, it was confirmed that the LiDAR has lower elevations that are submerged by the IWLs set for the simulation boundary conditions.	Generally appropriate. Topographic edits could be made to eliminate triangulation issues in the LiDAR, particularly in the creek channels but ultimately this is unlikely to affect project outcomes given the downstream location.
4.2.3.6	**Bathymetry**: The model includes a portion of hydrographic survey of the Black River channel, however its extent is relatively limited, covering 2km upstream from the rivermouth. The remainder of the rivers and creeks do not have any representation of bathymetry, however it is recognised that this data is not available. No other topographic modifications have been included to enforce an estimation of bathymetry in these main channels. At the Black River there are some higher elevations from the LiDAR, outside of the extent of the bathymetric survey, that are higher than the default elevation set adjacent to this. This has created some ridges that could have been merged with a topographic modification. It is not expected to significantly impact results, these areas are submerged by the IWL applied to the simulations.	Reporting would benefit from discussion on the necessity (or lack thereof) for inclusion of data or other assumptions about bathymetry. The impact of unavailable bathymetry is unknown but is potentially not significant for larger events that are largely out of bank. It may have a greater impact on smaller events however.
4.2.3.7	**Default Elevations**: A default elevation of -0.6m has been applied to the model. This infills areas where there are null values in the base LiDAR datasets, primarily at the ocean. This is appropriate as it merges well with the LiDAR at the Bluewater and Althaus Creek mouths. At the Black River there some higher elevations from the LiDAR, outside of the extent of the bathymetric survey, that this default elevation does not merge well to. It is not expected to significantly impact results, these areas are submerged by the IWL applied to the simulations.	Appropriate.
4.2.3.8	**Fill embankments**: Where the LiDAR incorrectly filtered out embankments, TUFLOW 2d_zsh terrain modifiers have been used to infill the embankments.	Appropriate.

ID	BMT Observation	BMT Recommendation
	Whilst we have confirmed that such embankments have been infilled, we can only assume they represent the correct levels.	
4.2.3.9	**Enforce crests**: Road and rail crests have been enforced with TUFLOW 2d_zsh terrain modifiers. It was confirmed in checkfiles that the major flow-controlling routes across the floodplain have been enforced. It is assumed that the control elevations have been inspected from the base LiDAR.	Appropriate.
4.2.3.10	**Watercourse channels**: No TUFLOW "gully" 2d_zsh terrain modifiers have been included to enforce the bed of drainage paths/watercourses. This may have previously commonly been required where the model resolution is insufficient to effectively capture the watercourse inverts, unrealistically obstructing the free drainage of runoff. However, the application of sub-grid sampling accounts for this, and is not recommended to be used in conjunction with gully modifiers.	Appropriate.
4.2.3.11	**Bridges**: Bridges have been included as TUFLOW layered flow constriction elements (2d_lfcsh). A blockage dependent scenario is used to call a duplicated file, with increase L1 FLC values for the blockage sensitivity (see Item 4.4.1.3). Some bridge details are documented in the report (soffit and deck elevation, and length) but reporting does not state methodology of the values adopted for blockage and constriction factors in each layer of the element. The "CUMULATE" option has been set to override the default loss approach – it is unclear why this was adopted but is no longer the default approach as it can overstate losses when bridges are drowned out All bridges have been included as line type 2d_lfcsh elements, which require a total FLC across the structure be specified for each relevant layer. TUFLOW will automatically divide the FLC by the number of cell faces selected by a 'wide' line. It appears that the FLC values have been entered as per metre length (in flow direction), which is only required for polygon elements. The values entered appear correct if they are multiplied by the line width: i.e. a total structure FLC for the deck of ~1.5 (consistent with the value of 1.56 typically used), and 0.5 for any the railings. Values for the total sub-structure FLC range from around 0.1 to 0.4, which are within the expected range. Due to the mismatch in FLC unit for the 2d_lfcsh geometry, these FLC/m values entered are being further reduced (as evident in the lfcsh_uvpt checkfile), resulting in an underestimation of losses across bridges. TUFLOW also recommends that the FLC values calculated for the sub-structure (in accordance with Hydraulics of Bridge Waterways) already accounts for the blockage provided by the piers, and hence additional blockage factor is not required to account for this as it may over-represent losses. This may	AECOM to review the form loss values applied to all layers, and blockage applied to L1, and assess the impact on results. Reporting would benefit from a brief discussion as to how sub-structure bridge form losses were derived or assumed. It is usual practice to calculate these in accordance with industry standard publications such as "Hydraulic Design of Waterway Structures" (Austroads, 2019). It is noted that the values appear within the expected range (when considering what appears to have been intended to be applied for the entire structure).

ID	BMT Observation	BMT Recommendation
	lead to slightly conservative results, however may be balanced by the low FLC values inadvertently applied. The HEC-RAS 1D model of key structures appears to verify the losses applied.	
4.2.3.12	**Initial water level of dams:** The model area includes numerous dams. Water levels have not been set for any dams, so the LiDAR level picked up from the water surface will be enforced as a "ground" level. A conservative approach would be to assume these dams are at full supply level (set with GIS IWL functionality) and not contributing to additional storage and detention of runoff from the catchment, however it is recognised this data may not be available. The base LiDAR topography picks up approximate water levels in the dams at the time of capture.	Reporting would benefit from discussion on the necessity (or lack thereof) for including a conservative dam "full supply" assumption. It is not expected that this has a significant impact on results, however there would likely be a greater impact in smaller events.

4.2.4 TUFLOW Materials File (TMF)

Table 4-5 Hydraulic Model – TUFLOW Materials File

ID	BMT Observation	BMT Recommendation
4.2.4.1	The DEM_M was inspected against the Mat IDs specified in the TMF, to ascertain which of the numerous listed materials had been applied. There is a substantial number of redundant IDs in the TMF that are not referenced spatially at all. Closer inspection of the DEM_M additionally indicates that many of these IDs are for relatively minor areas that would appear to sufficiently be captured in other categories. The model configuration would benefit from simplifying the Mat IDs and TMF to remove redundant classifications. The TMF appeared to generally contain the values as per reporting. These values are within the standard range of Manning's n roughness values, and are considered appropriate. A sufficient range of values has been defined to adequately define the hydraulic characteristics for the model. The TMF also defines material-dependent rainfall losses for calibration, and for design through TUFLOW variables. These losses are defined by land use type and apply to parts of the model where direct rainfall has been used in place of hydrologic model inputs. Design rainfall losses appear to generally be configured appropriately and assigned appropriate values but their derivation and method of application should be reported on. There are however significant areas defined as Mat IDs 106, 107, 108,110 and 401, and some other relatively minor areas such as Mat ID 201 and 207, which do not appear to have appropriate rainfall losses specified (in the TMF) for either calibration or design. These land use types are considered as pervious (for example ID 110 corresponds to grass) but under the model set-up there are only minor	Materials dependent losses, required for direct rainfall application, do not appear to have been specified for some of the referenced pervious Mat IDs, which cover a significant spatial area of the model. AECOM to confirm the sensitivity of model results to applying a losses to these areas, and consider implications for study results. Reporting would benefit from documentation of the event and duration dependent ARR losses applied for the direct rainfall design events.

ID	BMT Observation	BMT Recommendation
	initial losses removed from the direct rainfall hyetographs and no continuing losses that are applied to these areas. Local inflow volumes would therefore be considered conservative (overestimated).	

4.2.5 TUFLOW Read File (TRD)

Table 4-6 TUFLOW Read File

ID	BMT Observation	BMT Recommendation
4.2.5.1	A separate control file has been created to set the event and duration dependant initial and continuing rainfall loss variables, and appears to be configured appropriately. These variables are then implemented on a materials-dependant basis in the TMF for areas where direct rainfall is applied. See TMF Section 4.2.4 for more comments. No discussion or summary of applied design event losses has been included in the reporting, therefore it is not clear if the values set are appropriate.	Reporting would benefit from documentation of the event and duration dependent ARR losses applied for the direct rainfall design events.

4.2.6 TUFLOW Boundary File (TBC)

Table 4-7 Hydraulic Model – TUFLOW Boundary File

ID	BMT Observation	BMT Recommendation
4.2.6.1	**Downstream boundary**: The tidal downstream boundary is configured as a 2d_bc HT type (level vs time), digitised snapped to the active code boundary. Numerous 2d_bc HQ normal flow boundaries have been applied at the north-west and south-east active code extent, to allow runoff and floodwaters which overtop into neighbouring catchments to drain away freely. This an appropriate approach, and the boundaries have generally been configured appropriately. However, some on the north-western active code extent could have been adjusted to be digitised perpendicular to the drainage direction, and a number are of an insufficient length to capture the full flowpath in the largest events. They are considered likely to be set at an appropriate distance away from the catchment boundary to not affect results at the point of overtopping. It is noted that the direct rainfall polygon does not extend over the area at the south-east active code extent, so the flowpaths in this area are not representative of design flows, only of the overtopping volumes from the main study catchment area. It is noted that mapping has been appropriately masked to exclude these areas.	Generally appropriate. Reporting would benefit from additional detail/explanation on the model configuration for the 2d_bc HQ boundaries and the reliability/applicability of results in the areas outside of the main study catchment areas that may be impacted by these boundary/code assumptions.

ID	BMT Observation	BMT Recommendation
	The boundary elements are correctly linked to relevant source data in the scenario-dependent bc_dbases (see Section 4.2.8 for further discussion).	
4.2.6.2	**External Inflows**: The external boundaries are configured as a 2d_bc QT type (flow vs time), digitised snapped to the active code boundary. The boundary elements are correctly linked to source data for the relevant catchment ID in the scenario-dependent bc_dbase (see Section 4.2.8 for further discussion), and to "Total flow" .tot XP-RAFTS outputs. Some of the boundary elements are not of a sufficient length to cover the full flow path in larger events, particularly for main inflows such as from catchments BW11 from the 1% AEP and rarer. Other inflows are mainly only of insufficient length in the OPMF. This may have some limited impact on results adjacent to this boundaries, but is not expected to significantly impact the results overall.	Generally appropriate. Consider whether boundaries are digitised appropriately relative to flow widths.
4.2.6.3	**Source-Area Inflows**: The 2d_sa source area inflows are generally being applied near the downstream end of each subcatchment, which is considered appropriate. The boundary elements are correctly linked to source data for the relevant catchment ID in the scenario-dependent bc_dbases (see Section 4.2.8 for further discussion), and to the "Local flow" .loc XP-RAFTS outputs.	Appropriate.
4.2.6.4	**Direct Rainfall Inflows**: The direct rainfall inflows are applied as 2d_rf polygon(s). Rainfall inputs have been confirmed to be correctly linked to event and duration dependent hyetograph CSVs in the scenario-dependent bc_dbases. The hyetographs were confirmed to be configured with 0 values at first and last timesteps as recommended by TUFLOW. Reporting documents the methodology of applying the direct rainfall boundaries for calibration (Thiessen distribution for the Jan 2019 event), however does not document the gauge used for the Jan 1998 verification, nor provide relevant ARR2019 parameters and methodology for applying design events (appears to be for single IFD location). It therefore cannot be completely confirmed that the input hyetographs are correct. Where 2d_rf polygons border a catchment that is not represented with direct rainfall, care should be taken that 2d_rf polygons are aligned sufficiently accurately with topographic data (or be inset from the subcatchment boundaries), to ensure that they do not inadvertently extend into neighbouring catchments. Where the boundaries are not configured exactly along the crest of a subcatchment (in accordance with the base LiDAR topography), the 2d_rf polygon may sometimes apply over model cells that drain into the neighbouring catchment, causing a “trickling” effect flowpath in mapping that may be misrepresentative of design flows. With the current model configuration, this is only evident in	Reporting requires additional detail/explanation on the application methodology and parameterisation of the direct rainfall, particularly in relation to ARR2019 compliance.

ID	BMT Observation	BMT Recommendation
	catchment B6-a-1, H3, H2, BW15 and BW11 where they border 2d_rf polygons, and the effect is very minimal and would not significantly impact results outside of these catchment area edges.	
4.2.6.5	**SX (1D-2D connection):** All 1d SX connections utilise the Z flag to lower 2D boundary cell elevations to sit below the 1d channel invert levels. The TLF log file/messages layer identifies numerous WARNING 2118 (where the cell elevation is lowered by more than 0.3m). Spot checking of these locations shows many that are around, or higher than, 1m. Poorly positioned 2d_bc SX cells too close to an enforced embankment breakline may inadvertently lower it, and cells that inadvertently create a “hole” in the topography may contribute to reduced timestepping and slower simulations. It is recommended by TUFLOW that a sufficient number of cells must be selected to represent 1-1.5 times the structure width (consistent at both upstream and downstream ends). Only a set of two large culvert structures utilised a 2d_bc SX line type element to select the appropriate number of 1D-2D boundary cells that represent the width of the structure. The remainder of culverts and pipes were connected to 2d_bc SX point type elements. At the grid resolution of 5m, a single SX cell connection would be only appropriate for any structures with a total width of no more than 5m. The nwk_C check file was inspected, and 51 culverts/pipes that have a combined width (accounting for number of barrels as required) of more than 5m were connected to insufficient cells via the point 2d_bc SX . This limits the flow into the structure to the width of the selected cells.	Review WARNING 2118 messages and confirm that the Z flag, in combination with the positioning of the boundary cells, has not excessively lowered topography creating any unacceptable holes, or breaks in embankment crests. Review the number of 2d_bc SX cells connected to large culvert/pipe structures, ensuring a sufficient 2D width is selected to exceed the total structure 1d width. AECOM to confirm the sensitivity of model results to this issue, and consider implications for study results.

4.2.7 ESTRY Control File (ECF)

Table 4-8 Hydraulic Model – ESTRY Control File

ID	BMT Observation	BMT Recommendation
4.2.7.1	**Timestep**: The maximum 1D timestep is set. HPC uses adaptive timestepping thereafter by default.	Appropriate.
4.2.7.2	**Manholes:** Manholes at All Culvert Junctions is set to OFF, which will prevent any automatically generated manholes and associated losses. It is noted that a 1d_mh layer has been included to assign Engelund losses to pipe junctions in the urban pipe network. However these appear to be assigned only to junctions where there are no pits also connected. Pit channels are not included in any of the calculations for determining manhole energy losses. The absence of any automatically generated or manually assigned manholes at the pipe junctions that are connected to pits is considered the least conservative energy loss approach, and may understate energy losses at these junctions, however the impact to results is not expected to be significant. The loss outputs (e.g. _TSL GIS layer) can be reviewed to ensure they are appropriate. If the Manholes at All Culvert Junctions command was left ON (default), this would have retained additional automatic manholes at the pit locations, and the 1d_mh elements would override any automatically created manholes.	Generally appropriate. Review loss outputs to ensure they are as intended.
4.2.7.3	**Pipe/Culvert Locations**: It is assumed that IDs, dimension data and spatial locations of culvert/pipe elements has been correctly assigned to TUFLOW as per the supplied network data - review of the base dataset is outside of BMT's scope. Cross drainage elements appear to have been appropriately and consistently included where embankments cross watercourses.	Appropriate.
4.2.7.4	**Pipe/Culvert Mannings Roughness:** Inspection of the nwk_C checkfile shows a Manning's N roughness of 0.012- 0.013 has been applied to all culverts. Assuming concrete pipes/culverts, then this value is typical and industry-accepted.	Appropriate
4.2.7.5	**Pipe/Culvert Lengths**: It is assumed that dimension data has been correctly assigned to TUFLOW as per the supplied network data - review of the base dataset is outside of BMT's scope. Checkfiles were inspected for any unusually short or long elements, none were found to be inappropriate when measured with GIS.	Appropriate.

ID	BMT Observation	BMT Recommendation
4.2.7.6	**Pipe/Culvert Diameters**: AECOM reporting identifies that culverts/pipes were included "if the diameter is equal or greater than 600mm or if invert level details were present. Pipe diameters in the model vary from 225mm to 1500mm". This is a reasonable assumption given the scale of modelling and purpose. Confirmed that included culverts/pipes were consistent with this approach. Checkfiles were inspected for any diameters and number of barrels that resulted in a total structure width that was excessive. The elements with the largest total width were manually inspected and confirmed to be appropriate for the surrounding topography. However, many were found to have insufficient boundary cells connected (see Item 4.2.6.5). There are 28 elements in the culverts layer than do not have any data, and are not connected to the 2D domain.	Generally appropriate. Check elements that have no relevant attribute data and confirm intended.
4.2.7.7	**Pipe/Culvert Loss Coefficients**: Recommended TUFLOW values for entry and exit loss and height and width contraction coefficients have been correctly applied to circular and rectangular culverts/pipes.	Appropriate.
4.2.7.8	**Pipe/Culvert Gradients**: Confirmed no adverse gradients for individual 1d_nwk elements. For the elements with the highest gradient, it was confirmed that this generally appeared appropriate with the surrounding topography. P1112 has no DS_invert, and as such an unrealistic slope, plus its Z flag SX connection has created a 16m hole in the topography (discussed in Item 4.2.6.5).	Appropriate.
4.2.7.9	**Pipe/Culvert Blockage**: No blockage is assigned to the base pipe or culvert 1d_nwk elements, however a blockage dependent scenario is used to call a duplicated culvert file, that applies percentage blockage in the relevant attribute for the blockage sensitivity (see Item 4.4.1.3).	Appropriate.
4.2.7.10	**Pits and pit inlet database**: 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 - review of the base dataset is outside of BMTs scope. Pits appear to be appropriately configured.	Appropriate.

4.2.8 Boundary Condition Database (bc_dbase.csv)

Table 4-9 Hydraulic Model – Boundary Condition Database

ID	BMT Observation	BMT Recommendation
4.2.8.1	**Scenarios**: Several bc_dbases are configured to be called from the TCF, dependent on a given scenario. Each bc_dbase was confirmed to correctly contain the relevant links/data values for that specific scenario. Confirmed that the boundary source 'name' called the corresponding data column of the same name from the loc and tot XP-RAFTS input files. Confirmed that the boundary source 'name' was consistent across all relevant scenario bc_dbases. Each bc_dbase is configured correctly, however it is noted that the use of .ts1 groups is generally beneficial for reducing input file sizes and supporting neater bc_dbases.	Improvement can be made with the use of ts1 groups/file types for the hydrologic inputs, drastically reducing the number of required lines in the bc_dbase. Updates would be required in the 2d_sa and 2d_Rf GIS layers in combination with this.
4.2.8.2	**Downstream Boundary**: Confirmed that the appropriate data value (design events) and source (calibration events) for each scenario, as specified in reporting Section 4.2.3, is correctly linked to the 2d_bc HT downstream tidal boundary. It is noted that as the tidal boundary was applied as a constant elevation in each scenario, this value could have been directly specified in the bc_dbase, simplifying the configuration. A constant tidal boundary, reported as being the peak predicted tidal level for the 2019 event, was adopted in the both the 2019 and the 1998 events. It is reported that flood levels were insensitive to a varying tidal boundary. On the basis of this sensitivity outcome, this approach is considered appropriate. 2d_bc HQ normal flow boundaries have been appropriately applied to allow floodwaters which overtop into neighbouring catchments to drain away.	Minor text amendments required in Section 4.2.3: Clarify text and table that there are two climate change boundaries tested – 0.8m and 1.1m. Adjust values to make sense: "…increase of 0.8 m sea level rise to 2100 (2.354 mAHD)." Adjust values to make sense: "…future 1% AEP storm tide level of 3.61 mAHD"
4.2.8.3	**Inflows**: Confirmed that the appropriate input files are correctly linked in each scenario's bc_dbase. The names for external 2d_bc QT boundaries correctly link to .tot files, and 2d_SA boundaries to .loc files. BMT do not have access to the raw rainfall data for calibration events to confirm the appropriate values and period of data has been applied. Section 4.2.3 Boundary Conditions documents the climate change scenario downstream boundary conditions, but makes no mention of climate change conditions of rainfall/XP-RAFTS flows. It is noted	Reporting would benefit by adding reference to the climate change parameter applied to rainfall/XP-RAFTS models in Section 4.2.3. Suggested to hardcode the climate change direct rainfall

ID	BMT Observation	BMT Recommendation
	that a scaling factor of 1.154 has been appropriately applied to the direct rainfall 2d_rf boundary in the relevant climate change scenario bc_dbase, consistent with reporting scaling (RCP 8.5 2090) in Section 5.3 Climate Change Sensitivity Analysis. The climate change direct rainfall 2d_rf boundary is linked to a scenario dependent rainfall CSV, in addition to the direct scaling factor. It was confirmed that the source climate change and design rainfall CSVs contain identical data, so climate change allowance is not being double counted.	boundary to reference the base design rainfall inputs, to avoid unnecessary duplication of input files and reduce potential for misuse by future users. This does not impact on current results.

4.3 Model Calibration

Table 4-10 Hydraulic Model – Calibration

ID	BMT Observation	BMT Recommendation
4.3.1.1	Calibration scenarios were confirmed to have been appropriately configured in the modelling files. The results and AECOM's evaluation were reviewed and the hydraulic model calibration is considered acceptable. It is unclear how the QFES data was compared to hydraulic model results.	Provide additional commentary on how the hydraulic model results were compared to the QFES data, and the outcome of the comparison.

4.4 Sensitivity Analyses

Table 4-11 Hydraulic Model – Sensitivity analyses

ID	BMT Observation	BMT Recommendation
4.4.1.1	**Climate Change**: Changes to rainfall and tidal boundary parameters (as per reporting) were confirmed to have been implemented in modelling files appropriately, via alternative boundary conditions databases and TCF logic. Approach is consistent with ARR2019.	Clarify in Section 5.3 that peak results are an envelope of all durations.
4.4.1.2	**Joint Probability**: 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 TCF logic. Approach is consistent with ARR2019. Considering climate change sensitivity results were presented for two scenarios for differing increases to the static tidal boundary, and joint probability model files are configured for the two corresponding	Clarify in Section 5.4 which tidal boundary has been adopted for the climate change joint probability scenario.

ID	BMT Observation	BMT Recommendation
	climate change scenarios, it is not clear in Section 5.4 Joint Probability Coastal and Fluvial Flooding and the associated mapping which climate change boundary has been used.	
4.4.1.3	**Blockage**: Logic for the blockage sensitivity scenario was confirmed to generally be configured adequately in the control files, as per reporting, with alternative 1d_nwk (culvert) and 2d_lfcsh (bridge) layers called which has blockage percentages applied. A single duration/temporal pattern combination has been selected for each of the 1% and 10% AEP events assessed to represent a critical storm for the main rivers and urban area, however it is unclear if these are appropriate at the structures being assessed for blockage. It is noted that Variation for P309506 refers to "*evaluation of blockage risk to hydraulic structures associated with cross-drainage of Bruce Highway, North Coast Railway and key local roads*". Figure 41 shows the 270m and 540m duration storms are also critical at much of the highway and railway crossings in the 1% AEP event. No critical duration map is available for the 10% AEP event. It is noted that for several 2d_lfcsh bridges, the increase in sub-structure L1 blockage relative to the base case is not consistently 12.5%, as reported upon for multi span structures, and it not clear why. The reported process for selecting appropriate values for the blockage was cross checked. The floating debris mobility is reported as "Medium" however the reported description fits a High" categorisation as per ARR Table 6.6.3. It appears that the correct 1% AEP Debris Potential of "High" for floating debris has been subsequently selected anyway, based on a "High" mobility value. The sediment deposition blockage (ARR Table 6.6.7) required consideration of the AEP Adjusted Non-Floating Debris Potential, and it is not clear from the reporting whether this debris potential was assessed separately to the Floating debris potential. Debris Potential requires adjustment based on event AEP, which does not appear to have been considered for the 10% AEP event. Based on the description for culvert blockage, this would lower the blockage outcomes for 10% AEP event to 0%. The bridge blockage (assuming a "High" 1% Non-Floating Debris Potential) would be lowered to a "Medium" AEP Adjusted Non-Floating Debris Potential and an associated blockage of 15%/7.5% for singe/multi span structures.	Review blockage assessment – confirm/revise appropriate blockage percentages for non-floating vs floating, culverts vs bridges, 1% AEP event vs 10% AEP event. Provide additional justification in Section 5.5 for the choice of storm for the assessed events in relation to the structures being assessed for blockage. Consider if utilising TUFLOW's blockage matrix functionality is beneficial for specifying AEP-dependent blockage for the 1d_nwk culverts. Confirm appropriate blockage has been applied relative to the base case in the 2d_lfcsh bridge layer (if this configuration is retained). Should the base bridges layer also be altered due to issues identified in Item 4.2.3.11, then the equivalent changes will be required in this blockage scenario layer.

4.5 Results

Limited checks have been undertaken, with checks mostly focusing that peak flood levels increase with increasing flood rarity, model extent is sufficient to contain results i.e. no glass walling and no anomalous results.

Table 4-12 Hydraulic Model – Results

ID	BMT Observation	BMT Recommendation
4.5.1.1	**Types**: Mapping of enveloped peak flood depth, level, velocity and hazard (ZAEM1) results and development of a flood hazard overlay for current and future climate conditions have been undertaken as per the RFQ. Section 3.1.2 indicates that critical duration mapping is provided for all events, however Volume 2 presents only the 1% AEP event.	Update Section 3.1.2 to reflect which critical duration maps are presented in Volume 2, or provide critical durations for all events in Volume 2. This critical duration mapping could be updated to also reflect the temporal pattern of the critical duration, particularly where multiple of the same duration have been simulated.
4.5.1.2	**Filtering**: Reporting specifies that TUFLOW's internal Map Cutoff Depth of 0.1m has been applied. This is an appropriate approach when utilising direct rainfall functionality. It is noted that a Map Cutoff SGS 'Exact' command has also been included, which applies the same behaviour for map cutoff as if SGS were not used. Further post-processing with TCC's filtering criteria, as requested in the RFQ, which excludes flooding results in areas where the depth of flow is less than 100 mm unless the velocity is greater than 0.8 m/s, has not been applied to the raw results. It is assumed this was agreed with Council.	Appropriate.
4.5.1.3	**Gridded Outputs - General:** The supplied enveloped gridded map outputs for peak water surface elevation was inspected for all events, and results were confirmed to appropriately increase with event magnitude. The 1% AEP event was further inspected spot-checked for any abnormalities. Results generally appear reasonable. Select events and duration were resimulated to obtain a full set of results. Depth results indicate some flow accumulation in farm dams and behind minor road embankments, however this is considered a reasonable limitation based on the scope of the project. Review of the results in conjunction with the modelling elements confirm major cross drainage structures have been appropriately included.	Clarify in Section 5.1 that peak results are an envelope of all durations.

ID	BMT Observation	BMT Recommendation
4.5.1.4	**Gridded Outputs - Glass walling**: As discussed in the sections for TGC Code (Item 4.2.3.1) and Downstream boundary (Item 4.2.6.1), minor glass walling occurs in some places where the 2d_rf direct rainfall polygon is against the code boundary and not precisely aligned at the top of catchment, and at some 2d_bc HQ outflows that haven't been set wide enough to capture the full flowpath in the largest events. This is not expected to significantly affect results.	Recommendations as per Item 4.2.3.1 and Item 4.2.6.1.
4.5.1.5	**Messages log file**: No log files were provided. A limited number of events/scenarios were resimulated to produce additional log files. TUFLOW messages log files were spot checked for a variety of event magnitudes and scenarios for any errors, warnings or checks. No major warnings were found but it is recommended that 2D boundary cells for culverts are reviewed where they have been automatically lowered using the 'Z' flag (see Item 4.2.6.5). A number of warnings were also logged relating to 1d_nwk pipe/culvert configuration, which can generally be assumed to be reasonable assuming that the datasets implemented were fit-for-purpose (review of the base dataset is outside of BMT's scope). Warning 2468 should be reviewed for appropriate configuration/results (appears isolated to 2 culvert elements) Check/warning messages were consistent for the selected events/durations inspected.	Generally appropriate based on the information reviewed, but recommended that automatically lowered 2D culvert boundary cells are reviewed. Review Warning 2468.
4.5.1.6	**Stability**: Insufficient results and log files (e.g. minimum dt grids, hpc.dt.csv log files, TLF log files, plot output csvs for suitable locations) were available to adequately check stability. A limited number of events/scenarios were resimulated to produce additional log files. Peak flood level grids were spot checked around culverts 1D-2D connections: flood surfaces appeared stable, with no unexpected localised peaks that may indicate an instability in the solution. For the select events rerun, TUFLOW TLF, hpc.dt.csv log files and 1D culvert/pipe stability were spot checked for stability issues. HPC Repeated Timesteps summarised in the TLF can indicate stability issues if the number is excessive. In the inspected TLFs, the number of HPC HCN Repeated Timesteps were considered acceptable (a relatively small number is generally not of concern as repeating timesteps is intended to maintain stability), and no HPC NaN Repeated Timesteps were logged. In the inspected dt.csv log files, the minimum timesteps and the control numbers over time were plotted. The minimum timestep did not reduce to an excessively small value and didn't show excessive oscillation, which is acceptable. It is noted that the controlling timestep can be due to a	Generally appropriate based on the information reviewed.

ID	BMT Observation	BMT Recommendation
	single cell in the entire model, and model configuration issues such as an excessive lowering of topography by an SX Z flag may contribute to significant slowing of the simulation.	

4.6 Comparison to Previous Assessments

Table 4-13 Comparison to previous assessments

ID	BMT Observation	BMT Recommendation
4.6.1.1	The modelling methodology undertaken by AECOM is based on the ARR2019 guideline. The conclusions provided by AECOM on the causes for the differences in peak flood levels between the previous flood study (based on the ARR1987 guideline) and the current work (generally lowered in upper catchments and higher in the Black River channel), appear reasonable, however further supporting detail/analysis would assist in demonstrating this is appropriately justified.	Reporting would benefit from a comparison of the differences in design rainfall depths between ARR1987 and ARR2019, as this is a significant factor in the differing flood study peak levels for much of the catchment, and further detail on the implications of the revised FFA referenced to have contributed to the higher levels in Black River.

5 Conclusions

This peer review report has documented the review findings for the modelling contract undertaken by AECOM for the **Black River, Althaus Creek and Bluewater Creek** catchments, as part of Townsville City Council's Townsville Flood Modelling and Mapping Project.

The hydraulic modelling (including application of hydrologic modelling inputs derived by AECOM under a separate commission) was found to generally follow best-practice modelling approaches and techniques, conform with ARR2019 and be fit-for-purpose, however a number of moderate and more significant issues were found that should undergo further investigation.

Recommendations have been made which largely relate to providing further justification and/or documentation on elements of the modelling undertaken, however these are mostly not expected to result in any notable changes to modelling outcomes.

A number of issues of greater potential significance were identified. These should be further investigated for their potential impact on results, and addressed if necessary:

- A reduced cell wet/dry depth has not been applied, which is recommended for direct rainfall models.
- End times for events with durations of 60m, 90m, 120m and 180m did not appear to be sufficiently long enough to have captured the peak water level in the downstream areas of the model, based on an inspection of the Tmax_h outputs for all durations for a 50% and a 0.5% AEP event. All events/durations/scenarios should be confirmed to be simulated for a sufficient duration to capture peak levels int eh study area.
- Form loss coefficients applied to 2d_lfcsh bridge elements appear to have been incorrectly entered on a per metre basis, when they should be entered as the fixed loss for the entire structure for a line type element. This will cause TUFLOW to reduce the losses applied across the structure, compared to what was intended. Blockage has also been entered for the sub-structure, however advice from TUFLOW is that this may overestimate losses, as the FLC value should already account for the effect of piers. The magnitude of impact of these issues is unclear, particularly as they may offset each other.
- Large areas were assigned to Material IDs that appeared to be for pervious land use types, but had not been assigned appropriate material dependent losses reflective of pervious land in both the calibration and design events. These areas are within the application boundary for direct rainfall, so rainfall volumes applied to these land uses are likely overestimated.

6 References

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

AECOM (2021) Base-line Flooding Assessment – Black River Flood Study – Volume 1 - Report. Prepared for Townsville City Council, February 2020.

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