Peer review of Picnic Bay 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 **Picnic Bay Flood Study** prepared by AECOM under the Magnetic Island and Balgal Beach contract.

1.2 Supplied Data

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

- Picnic Bay Flood Study Base-line Flooding Assessment Volumes 1 and 2, Revision A dated 3 November 2021 (AECOM, 2021)
- Request for Quotation: Townsville Recalibrated Flood Modelling and Mapping – Magnetic Island & Balgal Beach (TCC, undated)

- Townsville Recalibrated Flood Modelling and Mapping Naming Convention Report (TCC, March 2020)
- Hydrologic Models:
  - PB_DES2.xp
  - PB_DES2_PMF.xp
  - Supporting GIS datasets
- Hydraulic Models:
  - PB-~s1~-~s2~-~e1~-~s3~~e2~.tcf

1.3 Peer Review Process

The peer review covers the following aspects:

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

We have utilised a traffic light system to indicate how significant an issue might be. Each issue is allocated a colour (green, yellow or red) in accordance with Table 1.1. Where a potential issue has been identified, we have provided our recommendations on how to address or further investigate the issue.

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

Table 1.1 Significance of Issue

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

1.4 Limitations

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

2 Modelling Overview

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

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

Model calibration was not undertaken as there are no water level gauges within the catchment. A verification of design flows has been performed against the Rational Method. A verification exercise has been performed on the hydraulic model by comparing modelled flood extents for the events of January/February 2019 and January 2020 against anecdotal data.

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

3 Hydrologic Assessment

3.1 Background

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

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

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

3.2 Hydrologic Review

General Comments

A check on the overall modelled catchment area showed a good match to the catchment area delineated in GIS (1.4km^2). Of the modelled catchment area, 0.1km^2 (around 7% of the total catchment) is attributed to impermeable land uses which appears appropriate based on aerial images.

A simple stream lag has been used for stream routing through the catchment. This is generally only appropriate in small urban catchments. When applied in rural catchments it may result in an under attenuation of flow. The majority of subareas are located within the area to which direct rainfall is applied in TUFLOW. Therefore, this issue within the hydrologic routing will not affect the TUFLOW results. Care should be exercised if using the hydrologic model for extracting flows in the lower reaches without the accompanying use of the TUFLOW model. It is recommended that the way in which lag times have been calculated is documented.

Model Calibration/Verification

The hydrologic model was simulated for the historic events which occurred in January/February 2019 and January 2020. There are no stream gauges within the catchment and so the calibration has been assessed based on applying the hydrologic model derived flows within the hydraulic model and comparing results (peak flood levels and extents) to available anecdotal data. This is reviewed under Section 4.3.

As a comparison of modelled hydrologic flows against recorded (rated) flows could not be undertaken, AECOM has performed a verification of the hydrologic design flows against the Probabilistic Rational Method.

Use of the Probabilistic Rational Method was common under the ARR1987 guideline, but current practice set out within ARR2019 no longer favours its use except at a localised lot scale[1]. This is primarily to do with the lack of scientific evidence underpinning for its runoff coefficient. It is noted

[1] ARR2019 advises that the Rational Method should only be applied within a catchment where more detailed analysis of rainfall runoff observations have defined its parameters (runoff coefficient and time of concentration).

however that the Queensland Urban Drainage Manual (QUDM) (IPWEAQ, 2017) still supports its use for urban catchments of less than 500 hectares or rural catchments of less than 25km^2 or as a checking tool for numerical models developed for small ungauged catchments.

BMT recognises that there is very limited historic data to calibrate/verify the model and therefore we consider that the use of the Rational Method as a tool to check for potential gross errors is acceptable.

AECOM has verified the hydrologic design event peak flows against the Rational Method at two nominated locations within the catchment. Generally the peak flow estimates compare reasonably well with no highlighted gross errors.

Overall, BMT is satisfied, given the limited data, that suitable verification has been performed.

3.3 Summary of Hydrologic Model Observations and Recommendations

In summary there were no observations of note and the set-up of the hydrologic XP-RAFTS model is appropriate for the study.

Table 3.1 Hydrologic Model Development and Calibration Summary

ID	BMT Observation	BMT Recommendation
3.1	Model uses simple catchment lagging and not routing. This is only recommended for small urban catchments	As the hydraulic model extent covers the majority of the catchment then this has reduced the uncertainty of this approach and a change to routing is not warranted at this late stage of the study.

4 Hydraulic Model Development and Calibration

4.1 Background

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

4.2 General Considerations

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

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

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

Naming Conventions

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

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

General Setup

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

The extent of the hydraulic model covers approximately 70% of the overall catchment and is sufficient to cover the main urban area of Picnic Bay.

4.3 Hydraulic Model Development and Calibration

Topography

The base topography is based on a 1m DEM of 2019 LiDAR data, defined in the model using a 5m grid. Modifications are made in the form of breaklines to improve representation of the base topography around structures and to reinforce road crest elevations. Some of the road centrelines applied in the model extend into areas which are not roads. An example of this is at the western end of Picnic Street. As the elevations applied to the road crests are based off LiDAR data then this won't have any notable effect on the model or modelling outcomes.

Materials

Based on a visual inspection of the land use delineation against available aerial imagery, the mapped land uses are generally appropriate. The land use layers are used to set the rainfall losses for the parts of the model to which direct rainfall is applied. This is discussed further in the section below on External Boundaries.

Generally the assigned Manning's n values are appropriate. The values applied for land use covering dense bushland (0.065) and for roads (0.011) are both low for their respective land uses and may result in underestimations of peak water levels. BMT recommends that these values are reviewed along with their potential to impact on results.

Structures

There are no bridges modelled within the 2D domain. All structures are represented in 1D. This is appropriate given that the structures are generally small relative to the model cell size.

There are 21 culverts included in the model. No issues were identified with these culverts.

An additional 10 stormwater pipes are included in the model, the majority of these representing the drainage network near the Picnic and Yule Street intersection. No issues were identified with the representation of the pipes in the model.

External Boundaries

The model downstream boundary is configured as a water level vs time (type HT) boundary snapped to the active code boundary.

Hydrologic model results are applied to the TUFLOW domain as 45 source area (type SA) boundaries. The majority of the SAs apply local catchment flows and three apply total catchment flows. The inflow locations were cross checked against the XP-RAFTS subareas and no issues were identified.

Direct rainfall is applied across the majority of the TUFLOW domain. Checks show that no local hydrologic inflows are applied within the area of direct rainfall and so there is no double accounting of flow.

Output Settings

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

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

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

Model Calibration

The hydraulic model was verified to two historic events which occurred in January/February 2019 and January 2020. As discussed in Section 2, there were no stream gauges to assist with model calibration. The approach taken was therefore to simulate recorded rainfall and compare hydraulic model output against anecdotal data.

The report provides a brief summary that the model results generally accord with the limited anecdotal data available. If available, BMT recommends that some additional detail for the January 2020 event is provided highlighting some examples of where the model results are consistent with observations from resident's reports.

4.4 Summary of Hydraulic Model Observations and Recommendations

Table 4.1 Hydraulic Model Development and Calibration Summary

ID	BMT Observation	BMT Recommendation
4.1	Naming conventions are not in strict accordance with requested naming convention by TCC	For consideration by TCC. In BMT's opinion the adopted naming remains clear, logical and allows TCC to easily identify it is a Horseshoe Bay model. We do recommend that a run ID is incorporated into the model name.
4.2	The Manning's n of 0.011 for roads and 0.065 for dense bushland are considered low.	BMT recommends that these Manning's n values are reviewed along with their potential to impact on results.
4.3	Results filtering is not strictly in adherence with TCC requested filtering criteria as it omits the velocity component.	Cutoff depth applied appears reasonable but TCC to review against requirements.
4.4	Reporting would benefit from examples of where model results accord with resident reports for the historic events modelled.	Include some examples of where the model results are consistent with observations from resident's reports

5 Determination of Design Floods

5.1 Overview

The approach to design flood estimation applied by AECOM uses approaches contained within the ARR2019 guideline. As no stream gauges exist within the catchment the approach relies upon design event simulation using the hydrologic and hydraulic models developed in the assessment.

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

5.2 Design Event Simulation

Design Parameters

A single IFD location appears to have been used to generate the direct rainfall. The IFD data has been correctly documented and applied.

It is not clear on what has been modelled/used for the PMP. BMT notes the following:

- The report states that the 1 hour PMP is critical at the mouth of Butler Creek (Table 6 of AECOM report).
- The supplied XP-RAFTS model contains a PMP rainfall depth for the 90 minute duration of 550mm. The 90 minute duration is the only storm included in the supplied model.
- Hydrologic model results for the 90 minute duration show no resulting flows. The no flow 90 minute PMP boundaries are also included in the boundary database for TUFLOW.
- The 90 minute temporal pattern applied in XP-RAFTS contains a number of leading zeros whereas the equivalent 90 minute pattern in the TUFLOW direct rainfall input does not contain these zeros. This will mean the applied storm in the TUFLOW SA inputs and TUFLOW direct rainfall input will effectively start at different times.
- The 60 minute storm is not specified in the supplied XP-RAFTS model. The 60 minute storm in the TUFLOW direct rainfall inputs appears to be missing one of the intervals. It is also distributed across a 90 minute period.
- The supplied TUFLOW results for the PMF include both the 90 minute and 60 minute storms. Enveloped results are not supplied so it is not clear if the 90 minute results have been used in any way. Regardless, the 90 minute results are erroneous as they do not contain any inflows outside of the zone of direct rainfall.

It is recommended that AECOM provide further clarity on what has been modelled/used for the PMF results. If only the 60 minute storm has been used then the supplied XP RAFTS model should include this storm and the temporal pattern applied in TUFLOW should be reviewed.

The report states that an areal reduction factor (ARF) has been applied based on the 'East Coast North' region. BMT notes that an ARF of 1.0 has been applied in the modelling essentially meaning that no areal reduction in rainfall has been applied. It is likely that the ARF of 1.0 has resulted due to the 'East Coast North' region not extending across Magnetic Island. As such no ARF parameters are available for catchments on Magnetic Island. If an ARF was to be applied BMT recommends that the 'East Coast

North' parameters are manually entered. However an ARF of 1.0 is a conservative approach and in BMTs opinion is suitable for the assessment. An ARF of 1.0 is also consistent with what has been applied in the direct rainfall.

An ensemble approach to temporal patterns has been applied as set out in ARR2019. Point temporal patterns have been applied as the catchment area is less than 75km^2.

With regards to rainfall losses the approach taken follows that given in ARR2019 whereby an initial storm loss is converted to an initial burst loss by accounting for pre-burst rainfall. For permeable areas an initial storm loss of 70mm is reported for both hydrology and hydraulic (direct rainfall) components of the modelling. The continuing loss is reported as being 2.5mm/h for permeable areas. These loss values differ from that specified in the ARR2019 datahub which lists a storm initial loss of 72mm and a continuing loss of 4mm/h. BMT notes that the adopted values better approximate the continuing loss values determined through model verification and agrees with their use.

The downstream boundary is specified as a constant level set at MHWS (1.1mAHD) for all design events. Use of MHWS is in accordance with the TCC Guideline.

Critical Duration / Event Selection

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

- Identification of the critical durations and temporal patterns has been undertaken using the hydraulic model. This has involved running full ensembles (10 events) for each duration/AEP combination and analysing the flood levels in every grid cell. It results in a significant number of simulations but is feasible due to the rapid simulation times of the model (typically less than 5 minutes).

- The process results in a peak design flood elevation surface effectively based on a statistical analysis of results in keeping with the ARR2019 approach at every grid cell. For a given AEP, this process first identifies the median flood level for each duration in every grid cell and then generates a flood surface based on the maximum of the median flood levels. A drawback of the approach is that a flood surface for any given AEP may be composed of results from many hydraulic model simulations and can impact the usability of the model from a practical point of view. Given the rapid simulation times, running many hydraulic simulations is unlikely to be an issue. However, this can cause complications when using the model for impact assessments. It is recommended that TCC/AECOM provide supplementary guidance on how to select appropriate events for flood impact assessments to avoid a variety of approaches being applied by third parties.

- The report does not state, but it is assumed that, the process for deriving other gridded flood surfaces (velocity, hazard etc) is the same as that used for peak level (a max of the median approach). For a given location and for a given AEP, it is possible that different model simulations have generated the peak flood level and the peak of another output variable eg velocity. This can cause complications when using the model outputs for purposes beyond the flood study. It is recommended that the supplementary guidance referred to in the above point also includes selection of events for outputs other than peak level

Sensitivity Analyses

Climate Change

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

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

Joint Probability Zone

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

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

Structure Blockage

A blockage assessment has been undertaken which is in accordance with ARR2019. This assessment has been undertaken on modelled culverts and pipes. Blockage factors of 60% have been applied in the 1% AEP event. A further assessment on the 50% AEP event applied a 40% blockage to the culverts. The report states that the applied blockage was 15% which is inconsistent with that modelled.

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

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

Design Simulation Results

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

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

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

- Counts of buildings within each AEP
- Water depth of main roads at selected crossings

- Commentary on what AEP inundates community buildings and infrastructure

5.3 Summary of Design Flood Estimation Recommendations

Table 5.1 Design Flood Estimation Summary

ID	BMT Observation	BMT Recommendation
5.1	It is not clear from reporting and supplied model files what duration has been used for the PMF. The report indicates 60 minutes but the supplied model files indicate 90 minutes. If 90 minutes has been used, there is an error in the derived flows. If only the 60 minute storm has been used then the supplied XP RAFTS model should include this storm and the temporal pattern applied in TUFLOW should be reviewed.	Clarify what duration has been modelled/used for the PMF results. Review the PMP temporal pattens applied in XP-RAFTS and TUFLOW (direct rainfall) for consistency. The 90 minute PMF XP-RAFTS inputs to TUFLOW contain no flows.
5.2	An ARF of 1 (no reduction) is applied. The report states ARFs from the East Coast North region are applied but this is not the case.	Update report to state an ARF of 1.0 is applied.
5.3	The approach to simulate all ensembles and durations to generate a flood surface of a given AEP can complicate approaches taken for flood impact assessments.	TCC/AECOM provide supplementary guidance on how to select appropriate events for impact assessments, including selection of events for outputs other than peak level.
5.4	Blockage sensitivity factors differ between report (15%) and modelled (40% and 60%).	Clarify in report what blockage factor has been applied.

6 Other Considerations

6.1 RPEQ Signoff

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

6.2 Structure Head Loss Verification

The RFQ requests that head losses against cross drainage structures (which have a moderate to significant impact on flooding within the study area) will need to be verified with a HEC-RAS model. No head loss verifications are presented by AECOM. It is assumed this is because there are no cross drainage structures which have a significant influence on flooding. It is BMT's opinion that there would be minimal benefit in cross checking head loss at individual structures unless there was significant head loss which could impact on urban areas

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
6.2	No head loss verification included in report	None. Assumed not required.

7 Conclusions

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

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

Observations and recommendations have been made by BMT on key aspects of the study with a summary of these tabulated in each section of this report. One significant issue was identified with the PMF event whereby a component of the model applies zero flow. It is not clear from the supplied data if these model results were used and so this is to be clarified.

No other significant issues were identified by BMT. A number of more minor issues were noted, the majority of which relate to requests for clarifications within the report.

8 References

AECOM (2022) Base-line Flooding Assessment – Picnic Bay Flood Study – Volume 1 and Volume 2 – Report (Revision A). Prepared for Townsville City Council, November 2021.

AIDR (2017) Managing the Floodplain: A Guide To Best Practice in Flood Risk Management in Australia, Handbook 7, third edition. Australian Institute of Disaster Resilience.

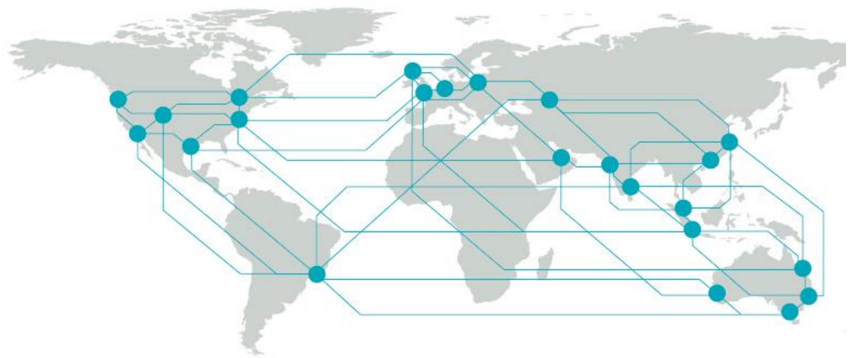
Austroads (2019) Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures June 2019.

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.

IPWEAQ (2017). Queensland Urban Drainage Manual (QUDM), 4th Edition prepared by Institute of Public Works Engineering Australasia, Queensland Division, 2016.

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

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



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