ISBN for HWRS 2025 is 978-1-925627-81-7

Beyond the event-based horizon: URBS models for long-term continuous simulation in the Darling Downs

Rhys Cullen[1], Lindsay Millard[1], Hayden Guse[1], Don Carroll[2] and Jagath Abeynayake[3],

WRM Water & Environment[1], Don Carroll Project Management[2],
Queensland Department of Transport and Main Roads (DTMR)[3]
*rcullen@wrmwater.com.au

ABSTRACT

Long-term hydrologic continuous simulation has typically been limited to daily water balance models, such as AWBM and SimHyd, or sub-daily models, including GR4H and MUSIC. Although these models can be successfully calibrated to observed data for a range of catchment sizes, there is no easy way to transition these models (and their parameters) to a traditional event-based hydrologic model. This can lead to discrepancies between flood quantiles estimated by continuous simulation models (CSM) and traditional event-based models for the same catchment.

The URBS hydrologic model was used to address the challenges of transitioning from CSM to event-based modelling for watercourses within the Darling Downs in southern central Queensland. The URBS model can be run in the following ways: continuous simulation, event-based simulation, Monte Carlo simulation, and design event simulation. The strength of the URBS model lies in the fact that routing parameters remain constant across all simulation modes, with only the loss model changing when using CSM.

This paper presents a case study demonstrating the successful conversion of event-based URBS models to CSM, calibration in continuous simulation and the validation of CSM results against Monte Carlo assessments from the same models. Thirteen URBS models, covering an area of over 85,000 km² and featuring 23 calibration gauges, were utilised in the study.

The study showed URBS CSM parameters can be successfully regionalised. The regionalised parameters also remained similar across adjacent catchments. The URBS model's CSM calibration parameters also performed well when tested against gauged discrete event hydrographs, at-site flood frequency analysis, and flow duration curves. Monte Carlo flood quantiles estimated by the URBS models were reconciled well with the CSM flood quantiles, providing confidence that future traditional design event assessments within these catchments will not yield significantly different peak flow estimates from the continuous simulation model.

ISBN: 978-1-925627-81-7

INTRODUCTION

Overview

In 2024-2025, the Queensland Department of Transport and Main Roads (TMR) undertook the Darling Downs District Flood Study (DDFS). The Darling Downs is traversed by a network of key inland freight routes that perform a vital economic function for Queensland and the nation, as well as providing essential connectivity and access to community services.

The purpose of the DDFS was to support the development of flood vision standards and resilience levels for each highway link and identify a prioritised list of infrastructure upgrades that will progressively improve the resilience of the existing network during flood events and deliver overall value for money. These routes include critical sections of the National Land Transport Network interconnected by sections of seven interlinked state-controlled highways, see Figure 1. The DDFS analysed 1,549 culverts and 57 bridges along 1,307 km of state-controlled highways. Hydrologic models are necessary to investigate flooding of the highway network, particularly where the highway network could be subject to flooding at numerous locations throughout the same catchment. Vitale (2017) outlined why assessment of flood travel time is vital for the economic assessment of a network link flood study.

In order to undertake long-term statistical assessments of the hydraulic performance of the structures (beyond that of a simple design event analysis), continuous simulation was used to estimate a 136-year sequence of hourly flows at each structure, which was then used as input to hydraulic models developed for the study. The URBS hydrologic model package, as described in Carroll (2021), was used to conduct the continuous hydrologic simulation for the study. One of the significant benefits of adopting URBS is that the study was able to utilise several existing, calibrated URBS models of the river basins within the study area. URBS also provides a straightforward process for transitioning from traditional event-based modelling to CSM, and vice versa, allowing the CSM URBS models developed for the study to be utilised in future location-specific business case flood studies.

This paper presents a case study demonstrating the successful conversion of event-based URBS models to CSM, calibration in continuous simulation and the validation of CSM results against Monte Carlo assessments from the same models. Thirteen URBS models, covering an area of over 85,000 km^2 and including 23 calibration gauges, were used in the study.

Defining the Problem

Unlike conventional design flood estimation, which focuses on individual crossings, continuous simulation enables the assessment of interdependence and relative timing of flood impacts across the network of highways. This allowed for more accurate calculations of statistics, such as Average Annual Time of Closure (AATOC) and Average Duration of Closure (ADC), for entire links, which are vital for economic analysis and prioritisation of upgrades.

Continuous simulation is a powerful method that can implicitly account for complex interactions such as event rainfalls, antecedent conditions and the behaviour of distributed systems sensitive to varying temporal and spatial scales of storms. Daily timestep CSMs are widely used to simulate the behaviour of water management systems; however, daily timestep datasets fail to capture the sub-daily rainfall variability that drives many hydrological and geomorphic processes. A disaggregation approach was used to generate a

ISBN: 978-1-925627-81-7

long, continuous time series of sub-daily (hourly) rainfall data. This was essential because observed sub-daily rainfall records are often too short or sparse to support the required continuous simulation periods (a continuous simulation period of over 100 years was necessary to provide confidence in the statistical outcomes of the study).

In previous applications of CSM models to flood modelling, TMR has identified differences between the design flood quantiles estimated by CSM models and those subsequently developed for the same catchments using traditional design event hydrologic models. Ideally, the design flood quantiles estimated by the CSM should be consistent with those estimated by a traditional design event hydrologic model.

This paper demonstrates how URBS, configured with the Recovering Initial Loss Model (RILM) in 64-bit mode, can accurately simulate long-duration streamflow. Model calibration and validation were performed by comparing simulated outputs against gauged records using event hydrographs, Flood Frequency Analysis (FFA), and flow duration curves.

URBS CSM model results were then validated against Monte Carlo Total Probability Theorem (TPT) estimates to demonstrate consistency in flood quantile estimates, and demonstrate that the CSM models can be easily converted to traditional hydrologic models, or that future hydrologic models of the same catchments will give similar results to the CSM.

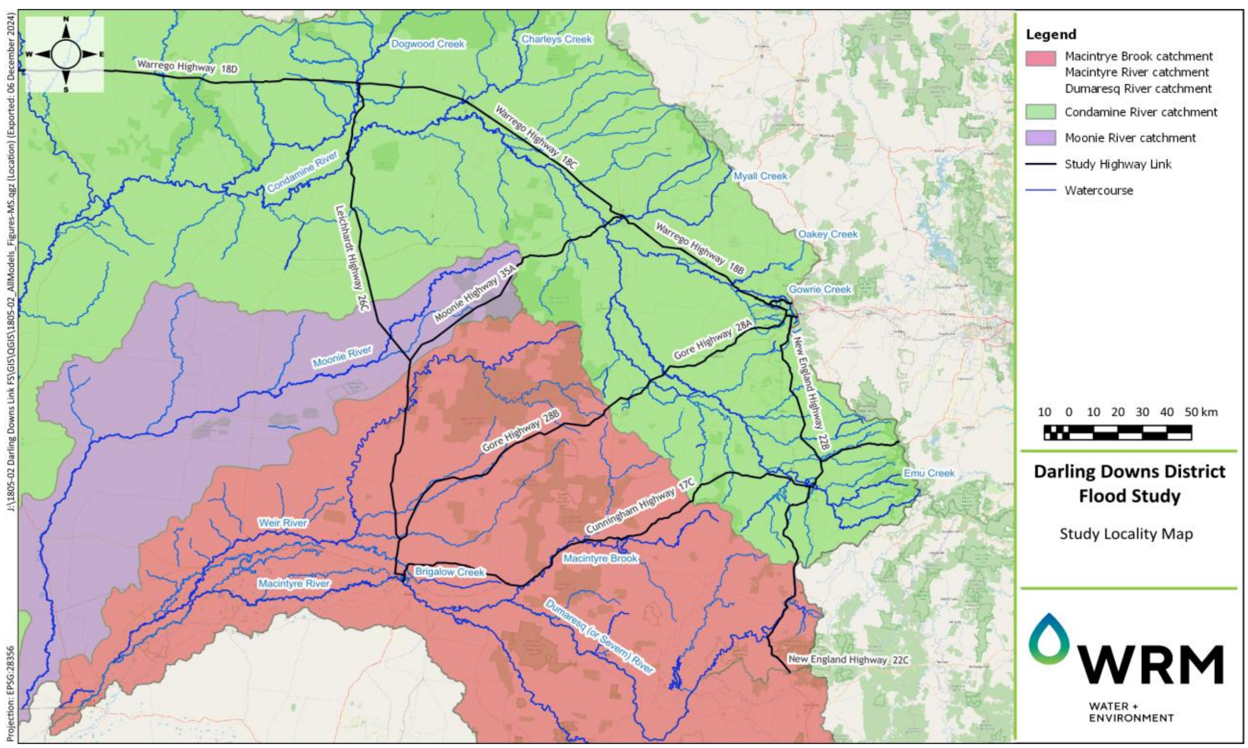

Figure 1. Project Locality

ISBN: 978-1-925627-81-7

METHODOLOGY

URBS software and rainfall inputs

The URBS hydrological model is a runoff-routing computer program that uses a network of conceptual storages to represent the routing of rainfall excess through a catchment. The URBS model was used in the 'split mode,' which enables the separate simulation of catchment and channel routing. Rainfall losses are subtracted from the total rainfall hyetograph to obtain rainfall excess. The rainfall excess is then routed through conceptual catchment storage to determine the local runoff hydrograph for each sub-catchment of the model before being added to the creek or river channel. Routing through the creek or river system uses the non-linear Muskingum method, whose lag time is assumed to be proportional to the stream length. Full details of the URBS model and its features are given in the URBS User Manual (Carroll, 2021).

Malone (2023) documented the extensive application of URBS software for flood forecasting and design flood studies. Malone catalogued and summarised the parameters from the calibration of 310 models throughout Australia. One key takeaway from Malone's 2023 paper was the promise shown by the Recovering Initial Loss Model (RILM) compared to the Initial and Continuing Loss (IL/CL) model. Malone concluded that RILM produced superior calibration, particularly in analysing long-duration multipeak events. RILM is an extension of the IL/CL model, allowing for recovery of the initial loss when rainfall rates on pervious areas are less than the continuing loss rate.

While URBS has had RILM and CSM functionality for some time, the previous releases were compiled for a 32-bit memory address, which limited the size of array calculations. This limitation was overcome by the 2024 release of URBS to a 64-bit version, allowing the model runs to experience a step change in temporal resolution and run duration, making it possible to simulate URBS models at sub-daily timesteps with representative climate records for simulation periods of over 100 years, provided suitable climatic inputs can be derived for such a simulation period.

URBS model development

Existing event-based calibrated URBS models were available for some of the major river basins in the DDFS study area; however, several new URBS models were also developed as part of the study. The existing URBS models had been previously calibrated to historic flood events using the IL/CL approach as part of other studies. The calibrated URBS subcatchment and channel storage routing parameters in the existing models were maintained, and the existing models switched from event-based to CSM. New URBS models developed as part of the DDFS were calibrated in continuous simulation mode only.

Running URBS CSM RILM requires additional parameters from traditional event-based URBS models to describe how soil moisture stores vary. The URBS continuous simulation loss module also requires a subarea rainfall (.r) file and a single evaporation (.pet) file described in the rainfall definition file (.rdf). Each URBS model subarea was assigned a 136-year hourly rainfall sequence. The initial release of URBS 64-bit only requires one evapotranspiration sequence per model vector file. While evapotranspiration does not vary as significantly as rainfall, future URBS development will allow individual evapotranspiration sequences to be assigned at each subarea. The following CSM variables then parameterise the URBS CSM:

- Initial loss (IL) [model initialisation state only].
- Continuing loss (CL).

ISBN: 978-1-925627-81-7

- Maximum Initial loss (ILmax).
- Initial loss recovery factor (RF).
- Maximum infiltration capacity (IF).
- Infiltration recovery (Kd).

A graphical representation of the URBS CSM's RILM is shown in Figure 2.

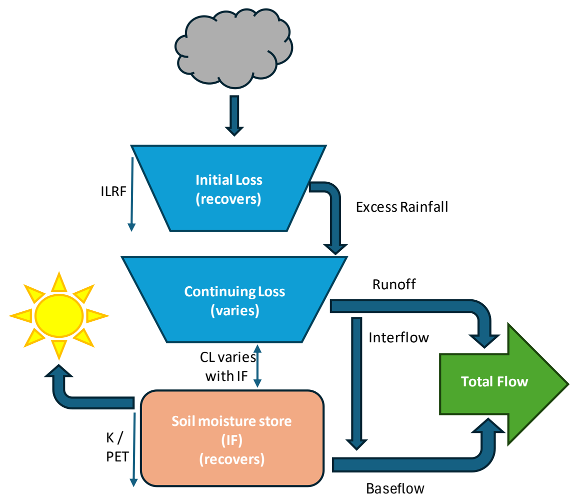

Figure 2. URBS recovering initial loss model

The CSM RILM parameters were calibrated by analysing the complete flow series against stream gauge-rated discharge hydrographs, flow duration curves, and FFA. The FFA was undertaken using FLIKE for the period of record available at the gauge, not the full generated flow series.

Input rainfall data

For the DDFS rainfall and climate data, gridded data products such as SILO Data Drill (Jeffrey et al., 2001) and BARRA-R2_v1 (Su et al., 2022) were used, as well as data from over 380 sub-daily rainfall stations and over 1,500 daily rainfall stations. Utilising as much observed rainfall data as possible in the CSM input sequences simplified calibration of the URBS models against the observed streamflow data.

To extend the sub-daily CSM rainfall input sequence, the method of fragments was employed (as detailed in Millard et al, 2025) to disaggregate daily rainfall into smaller intervals, which allowed for confirmation of the disaggregated rainfall's Intensity-Frequency-Duration (IFD) characteristics against observed sub-daily rainfall records and traditional Bureau of Meteorology (BOM) IFDs. This disaggregated daily rainfall data was then appended to the observed rainfall data to create a 136-year hourly rainfall sequence for each URBS model subcatchment.

A key part of the methodology involves comparing the IFD statistics of the 136-year hourly rainfall sequence with the BOM 2016 IFD curves throughout the study area. The comparison showed that the hourly rainfall database used as inputs to the URBS CSM had similar rainfall IFD statistics to the BOM 2016 IFD rainfalls, which is critical to ensuring consistency between CSM flood quantile estimates and flood

ISBN: 978-1-925627-81-7

quantiles estimated by Monte Carlo methods or traditional design event analysis. Figure 3 shows an example of the good match between the 136-year hourly rainfall sequence IFD and the BOM 2016 IFD at one of the pluviograph locations in the catchment. The at-site pluviograph data points are also shown.

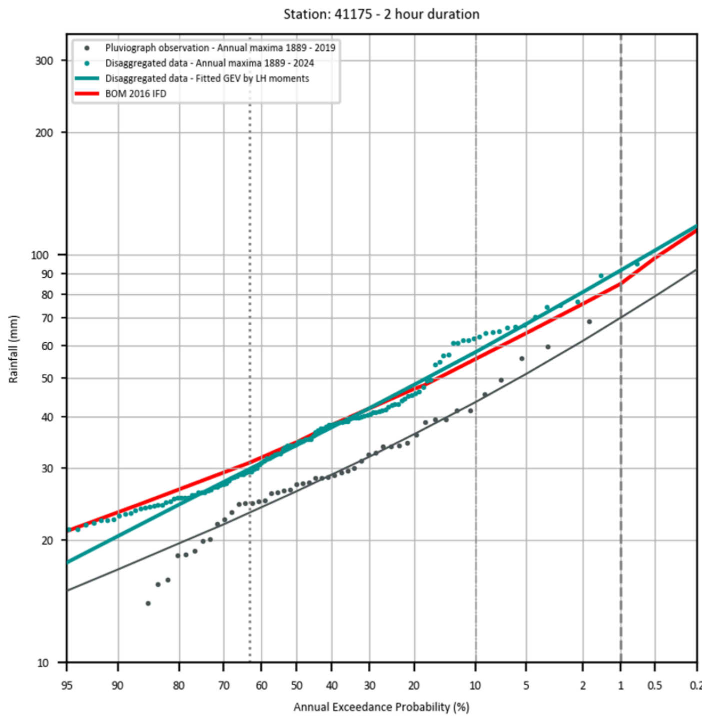

Figure 3. Comparison of 136-year rainfall sequence IFD to BOM 2016 IFD and at-site pluviograph data for a two-hour storm

CSM Calibration

The existing and new URBS models were calibrated in continuous simulation mode against rated discharge hydrographs, FFA and flow duration curves at key stream gauging stations. Six major flood events (1983, 1988, 1996, 2011, 2013, and 2022) were identified within the period from 1979 to 2024 and adopted as key events for model calibration. These events were selected due to the availability of rainfall data for model calibration. Events that occurred before 1974 had very limited available sub-daily rainfall data, limiting the calibration of the models.

Calibration to rated discharge hydrographs

Calibration to rated discharge hydrographs was generally undertaken by adjusting maximum initial loss and continuing initial loss. For new URBS models developed for the study, alpha, beta and m were also used for calibration. Figure 4 shows an example of the rated discharge hydrograph calibration for the URBS CSM model at a key gauge in the Condamine River catchment (Loudons Bridge). While Figure 4 shows distinct windows for ease of comparison, the modelled result series was drawn from the input files and parameters that commenced in 1889.

ISBN: 978-1-925627-81-7

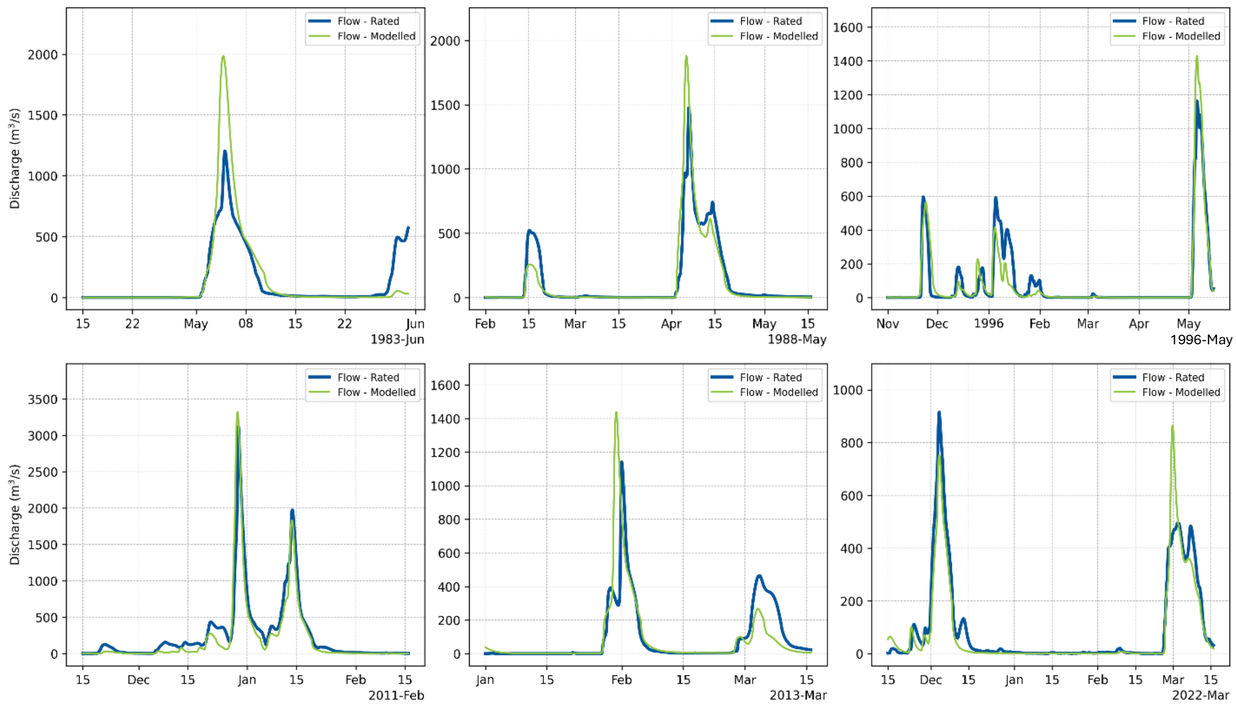

Figure 4. URBS CSM rated hydrograph calibration

Flood Frequency Analysis

Once the hydrograph calibration was deemed acceptable, FFAs based on annual maximum series from the available gauge record period and the model output over the same period were compared. Adjustments to the initial loss recovery factor, continuing loss, and maximum initial loss were made to improve the FFA match between the gauge record and model output, without substantially compromising the calibration of the rated hydrographs. Figure 5 shows a comparison of an URBS CSM model FFA against gauge FFA (Condamine River at Loudons Bridge).

Flow duration curve

Annual flow duration curves were derived from the rated flow records at each gauge. The model-predicted flow duration curves were compared to the gauge records, and the model output was calibrated primarily by adjusting the initial loss recovery factor, without compromising the FFA or event hydrograph calibration. Minor adjustments to the maximum initial loss and continuing loss were also made as part of the flow duration curve calibration.

Calibration of flow duration curves at each gauge focused on flow rates greater than the 20% AEP discharge based on the observed gauge FFA. Figure 5 shows a comparison between the URBS CSM flow duration curve and the gauge data flow duration curve (Condamine River at Loudons Bridge).

ISBN: 978-1-925627-81-7

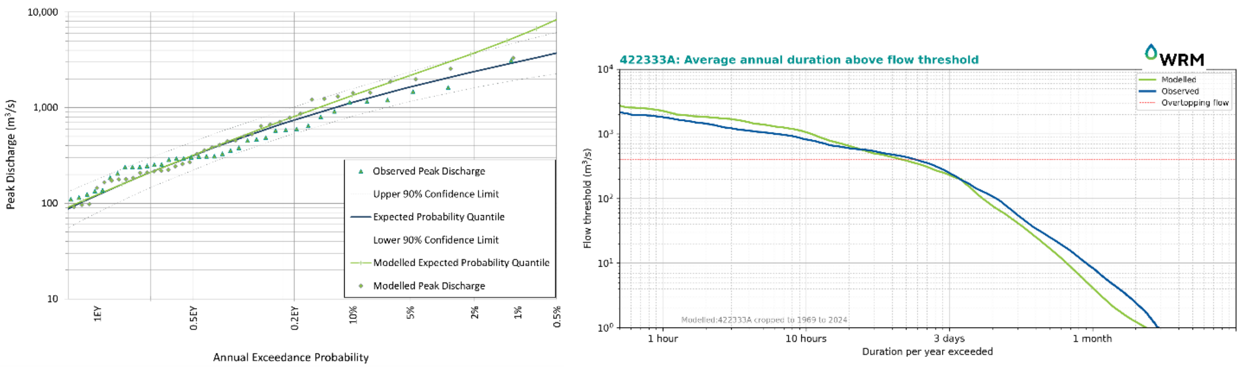

Figure 5. URBS CSM FFA calibration against gauge FFA and flow duration curve

RESULTS

Calibrated URBS model parameters

Table 1 presents the range of calibrated URBS CSM parameters for the 13 calibrated URBS models used in the study. The calibrated URBS model parameters show good regionalisation, with limited variation across the 85,000 km^2 of catchment area modelled as part of the study.

Table 1. Calibrated URBS CSM parameters

Parameter	Minimum	Maximum	Median
Alpha	0.4	0.6	0.45
Beta	1.2	4.0	1.5
M	0.6	0.8	0.715
N	0.8	1.0	0.9
Initial Loss (mm)	10	20	10
ILMax (mm)	50	120	75
IL Recover Factor	0.1	0.18	0.11
Continuing Loss (mm/hr)	1.3	2.5	1.55
IF (mm)	200	550	200
Kd	0.95	0.95	0.95

Validation to Monte Carlo and AR&R2019 Ensemble

The URBS CSM models were converted to traditional event-based models to validate them against Monte Carlo TPT analysis at all key gauges. AR&R datahub IL/CL losses were adopted as the starting point for the Monte Carlo validation, and then adjusted to improve the match between the flood quantile estimates from the two methods. Figure 6 shows the results of the validation at a key gauge in the Condamine River (Loudons Bridge), demonstrating the excellent correlation between the URBS CSM flood quantiles, gauge FFA and the Monte Carlo TPT flood quantiles. The correlation at all gauges varied, but generally fell within the gauge FFA confidence limits.

ISBN: 978-1-925627-81-7

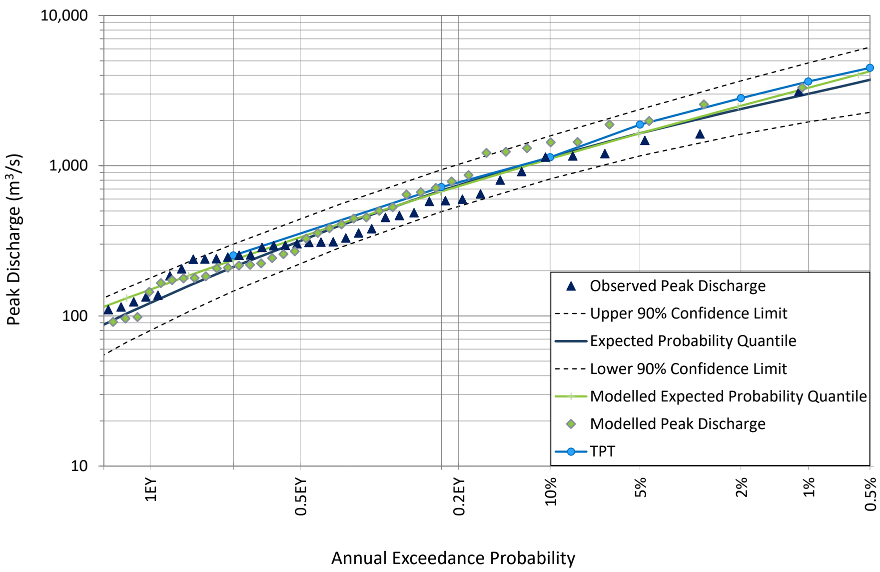

Figure 6. Comparison of URBS CSM, gauge FFA and Monte Carlo TPT flood quantiles

CONCLUSION

This paper successfully demonstrated a method for parameterising and calibrating a long-duration URBS model using the RILM and CSM approaches. By comparing modelled results to available gauge records through event hydrographs, Flood Frequency Analysis, and flow duration curve assessments, the authors have shown that this method provides a robust approach for validating continuous simulation outputs. The strong agreement observed between the CSM results and those from Monte Carlo TPT further increases confidence in the reliability of the generated flood quantiles. It should be noted that the URBS CSM accuracy in reliably representing the catchment response to flooding is subject to the length of the record and the spatial coverage of rainfall and streamflow data in the catchments.

ACKNOWLEDGEMENTS

The authors are grateful for the collaborative efforts of the extended project team, including Corey Baldwin, Trinity Graham, Greg Rogencamp, and TMR's project sponsors in the Southern Queensland Region, Emma Kirkby, and the Hydraulics Branch's Chris Russell and Jagath Abeynayake, for their partnership.

The dataset of the Australian rainfalls can be obtained from the Australian Bureau of Meteorology. Daily and sub-daily rainfalls are available at http://www.bom.gov.au/climate/data/. Intensity Frequency Duration (IFD) design rainfalls were obtained from the Australian Bureau of Meteorology at http://www.bom.gov.au/water/designRainfalls/revised-ifd/.

REFERENCES

Australian Bureau of Meteorology (2016). Design Rainfall Data System. http://www.bom.gov.au/water/designRainfalls/revised-ifd/.

Carroll, D. (2021). "URBS Unified River Basin Simulator. A Rainfall Runoff Routing Model for Flood

ISBN: 978-1-925627-81-7

Forecasting and Design" Version 6.65.

Jeffrey, S.J., Carter, J.O., Moodie, K.B. and Beswick, A.R. (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data, Environmental Modelling and Software, Vol 16/4, pp 309–330. DOI: 10.1016/S1364-8152(01)00008-1.

Malone, T., Carroll, D. (2023). Guidelines for URBS Routing Parameters Hydrology and Water Resources Symposium, Brisbane, 2023.

Millard, L., Batchelor, M. and Hamer, H. (2025). Hourly rainfall from daily records – a method of fragments now and into the future AusIMM Life of Mine | Mine Waste and Tailings Conference Brisbane 2025.

Chun-Hsu Su, Susan Rennie, Imtiaz Dharssi, Joshua Torrance, Andy Smith, Tan Le, Peter Steinle, Christian Stassen, Rob A. Warren, Carl Wang, John Le Marshall, (2022). BARRA2: Development of the next-generation Australian regional atmospheric reanalysis, Australian Government Bureau of Meteorology, August 2022.

Vitale, A. (2017). A Continuous Simulation Approach to Assessing Flood Closures for Major Transport Corridors, Floodplain Management Conference, Newcastle 2017. Available at https://www.floods.asn.au/client_images/1926316.pdf 1935187.pdf.

BIOGRAPHY

Rhys Cullen is a Director and Senior Principal Engineer at WRM with over 20 years of experience in water engineering, with a primary focus on developing hydrological and hydraulic models for large-scale catchment and infrastructure studies, urban developments, and mining projects. He has acted as technical director and an expert peer reviewer for flood studies and hydraulic assessments throughout Australia.

Lindsay Millard is a Principal Engineer at WRM whose expertise extends to flood and water resource modelling for natural resource management projects, the transport and mining sectors, and flood risk assessments for local Councils. He has led hydrologic and hydraulic modelling on multiple design flood studies and has extensive experience using industry software.

Hayden Guse is an Associate and Principal Engineer at WRM and has over 10 years' experience in surface water engineering. Hayden has significant experience in dam failure impact assessments, hydrology, extreme flood estimation, hydraulic modelling, surface water assessments in the coal seam gas, coal and mineral industries and flood damage estimation, including the development of flood stage-damage curves.

Don Carroll is the developer of the URBS model and has a 40 year engineering career in Australia and overseas, during which he has been involved in many water resources projects, including flood damage analysis, floodplain management, flood modelling and design flood hydrology. He has co/authored over 50 papers in his areas of expertise. Currently he is much involved with peer review for major flood study projects.

Jagath Abeynayake is a Principal Engineer at Queensland DTMR with over 20 years' of experience in the field of hydraulics and hydrology. Jagath oversaw the hydrology modelling undertaken for the DDFS and in his career at DTMR has provided expert review of linear infrastructure hydraulic design and climate change assessments.

ISBN: 978-1-925627-81-7