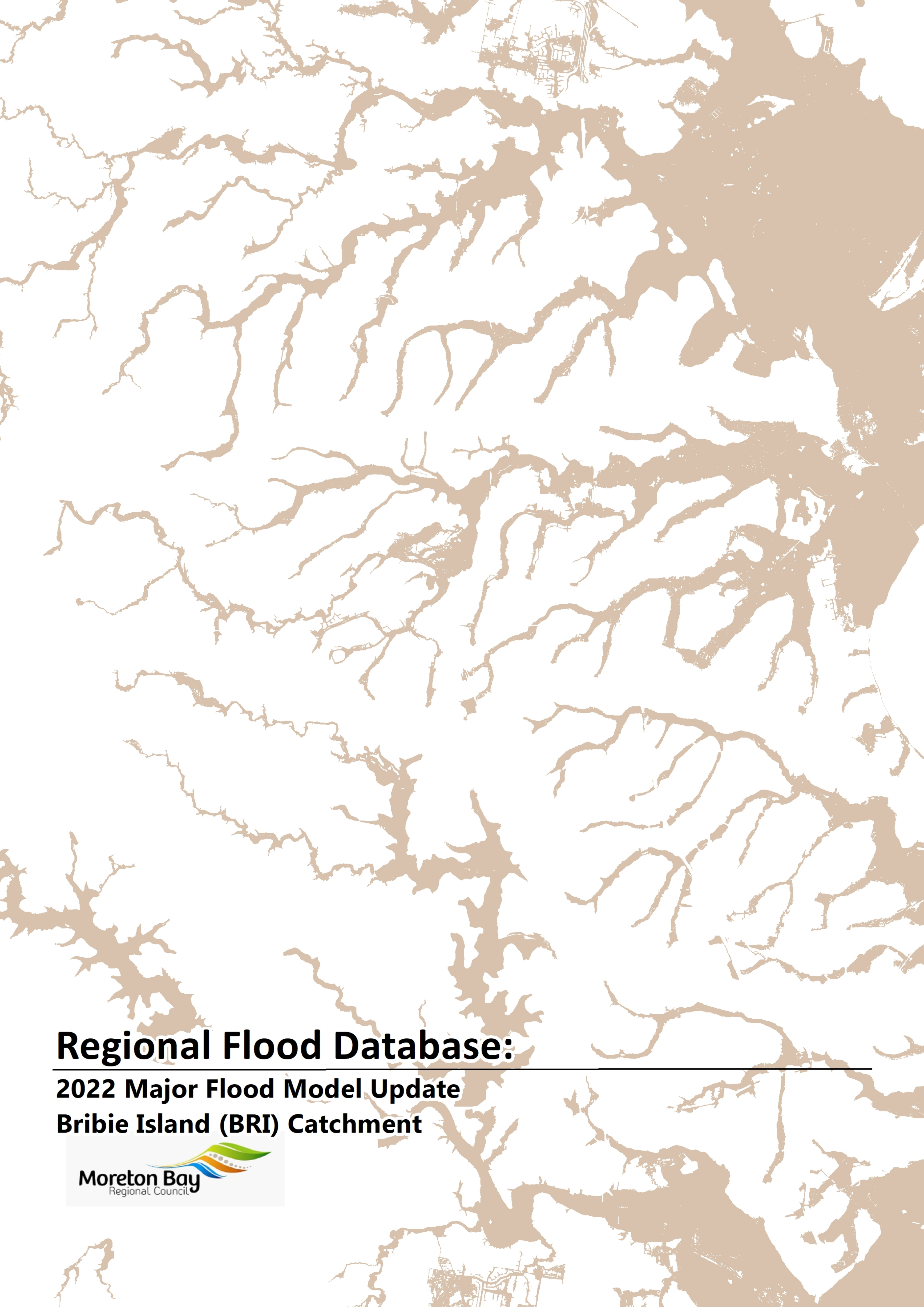

Regional Flood Database:

2022 Major Flood Model Update
Bribie Island (BRI) Catchment

Moreton Bay
Regional Council

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1 INTRODUCTION

Moreton Bay Regional Council (MBRC) is committed to continuously upgrading and enhancing its region wide hydrologic and hydraulic flood model library since its development in 2009, as part of the establishment of Council’s Regional Flood Database (RFD). The RFD flood model library is capable of seamless interaction with a spatial database to efficiently deliver detailed information about flood behaviour across the MBRC area and for the local community. This report details the outcomes of Stages 4 and 5 of the MBRC RFD for the Bribie Island Catchment. Figure 1-1 presents the location of the Bribie Island Catchment in the context of the wider Local Government Area (LGA) boundaries.

The primary objectives of the stage 4 study are:

- Update of the TUFLOW hydraulic models according to the outcomes of the Stage 1 project utilising the findings of the Stage 3 project.
- Model calibration and validation.
- Develop ‘hydraulic-equivalent’ hydrology (HEH) model.

The primary objectives of the Stage 5 study are:

- Design event modelling.
- Design event flood surface creation.

Figure 1-1 Bribie Island Locality

2 BACKGROUND

The methodology behind the RFD is primarily based on the national guideline for flood estimation, Australian Rainfall and Runoff 2019 (ARR 2019). This guideline underwent a major revision in 2016 and then a minor update in 2019. The updated guideline, together with recently collected new survey information (e.g. LiDAR) and recent flood information across the region, provides Council with an opportunity to undertake a major update to the RFD. This major update is being delivered in five stages, with Stages 1, 2 and 3 having been completed already:

- ***Stage 1 – Pilot Study*** – investigated the required/recommended modelling methodology changes for the RFD utilising the ARR 2019 guidelines.
- ***Stage 2 – Hydrography Landuse and Hydrology*** – entailed update of Council's floodplain roughness layers, catchment delineation and hydrology models.
- ***Stage 3 – Hydraulic model configuration investigation*** – was an internal investigation conducted internally by MBRC staff reviewing recently released software computation methods and capabilities to identify the potential application to the RFD hydraulic model setup.

With these three Stages complete, this study represents the subsequent stages 4 and 5 for the Bribie Island Catchment.

2.1 Catchment Description

The Bribie Island model area is characterised by a combination of high-density urban areas, canal systems with tidal influences and flat widespread floodplain flows within the National Park. Furthermore, there is no major river on Bribie Island with several individual tributaries draining west to the Pumicestone Passage as well as east to the Pacific Ocean.

3 2022 MAJOR FLOOD MODEL UPDATE DETAILS

3.1 ARR 2019

The previous RFD study had utilised hydrological and hydraulic data based on the guidance from Australian Rainfall and Runoff (ARR) 1987. However, in 2016, along with further updates in 2019, ARR underwent a significant revision, prompting the consideration of a broader range of hydrological variability in design estimates. This included the use of ensembles to run hydrological models, sampling different temporal patterns and other key hydrological parameters.

The ARR 2019 guidelines serve as a comprehensive and widely recognized resource, offering guidelines for estimating design flood characteristics across Australia. By incorporating the updates from ARR 2019 into the flood study, the analysis and assessments align with the most up-to-date understanding of rainfall patterns, hydrological processes, and flood behaviour.

By utilising the guidance provided in ARR 2019, this RFD update ensures it is based on the latest scientific knowledge and best practices in flood estimation. The updated guidelines consider various factors such as climate change projections, improved rainfall analysis techniques, and advancements in hydrological modelling. This incorporation enables a more accurate and robust assessment of flood risk, empowering stakeholders to make informed decisions pertaining to land-use planning, infrastructure design, and emergency management.

A key change introduced in ARR 2019 is the increased use of ensembles of design storms, specifically incorporating 10 temporal patterns per duration, with up to 100 storms per Annual Exceedance Probability (AEP). There is also a heightened sensitivity to Areal Reduction Factors (ARF) to account for spatial variation in rainfall. Given the time-intensive nature of simulating all storms and considering hydrologic variability within the hydraulic model, RFD Stage 1 guidance placed greater reliance on the hydrological models to identify critical storms.

For the selection of final flood surfaces, the hydrological models need to exhibit hydraulic equivalence, ensuring similarity between the hydrologic and hydraulic models. The TUFLOW model has been used to inform the hydrologic model storage and routing parameters giving a hydraulic equivalent hydrologic (HEH) model. The HEH model gives the ability to analyse ARR 2019 hydrologic variability at specific points of interest across the catchment without the need for a significant number of time-consuming hydraulic simulations. The following sections outline the relevant updates made to the hydrologic and hydraulic models to incorporate the ARR 2019 guidelines.

All ARR 2019 hydrological modelling was undertaken within the Catchment Simulation Solutions Storm Injector software version 1.3.7.

3.2 Rainfall Intensity-Frequency-Duration (IFD) Update

3.2.1 Intensities

Design flood estimates derived for the Bribie Island catchment have been based on the design IFD guidance outlined in ARR 2019 in combination with the updated LIMB 2020 high resolution IFD estimates. A sensitivity assessment was undertaken by Water Technology (2022) recommending the high-resolution dataset as it does appear to reduce flood levels significantly and is at a more suitable resolution for application to subcatchments throughout the MBRC region. IFDs were extracted at each subcatchment centroid through the Storminjector custom IFD ingest tool.

3.2.2 AR&R 2019 Datahub

Design rainfall parameters such as temporal patterns, pre-burst values and areal reduction factors were obtained from the ARR 2019 Data Hub (http://data.arr-software.org/). A parameter set at the closest location to the Bribie Island catchment is presented in Table 3-1 (noting that AR&R Datahub does not extract data on the island itself).

Table 3-1 ARR 2019 DataHub Parameters

Parameter	Value
Longitude	153.1010
Latitude	-27.0800
River Region	North East Coast
River Name	Maroochy River
ARF parameters	East Coast North
Storm Initial Losses (mm)	22
Storm Continuing Losses (mm/h)	2.6
Temporal Patterns	East Coast North Point

3.3 WBNM Hydrological Model Update

3.3.1 Subcatchment Updates

Catchment delineation and the hydrologic model was provided by MBRC. The provided WBNM model and associated GIS files were based on the Stage 2 – Hydrography Landuse and Hydrology Study. There were no alterations made to the subcatchment configurations as part of the Stage 4 and Stage 5 studies.

3.3.2 Impervious Areas

MBRC provided an Effective Impervious Area (EIA) raster dataset for the entire LGA for the purposes of updating percentage impervious values in the hydrologic models for both existing and future conditions. The EIA raster was created based on guides provided in the Stage 1 Report.

MBRC instructed that EIA calculations were not undertaken within the WBNM hydrologic model package or Storm Injector. An average calculation was undertaken on the provided rasters for each subcatchment to determine the EIA fraction to be applied in the WBNM model. Both current and ultimate conditions have been modelled. Where the ultimate EIA raster value was lower than the current EIA the current EIA value was adopted in the ultimate scenario.

3.3.3 Parameters

The Bribie Island catchment WBNM model has adopted the following runoff routing parameters.

- Catchment Lag parameter (C) = 1.6
- Impervious surface reduction lag factor = 0.1
- Catchment non-linearity parameter (m) = 0.77

The parameters were informed by the calibration outcomes of neighbouring catchments and they were further validated by simulation of a historical event and comparison to debris marks (see Sections 4 and 5).

3.3.4 Areal Reduction Factors

The pilot study recommended that the ARF be calculated at each POI and run the WBNM design event models. It was determined that by grouping POIs into ARF categories it would allow a more practical approach and reduce the number of WBNM simulations. Table 3-2 presents the categories applied to the Bribie Island model. Appendix D provides a table showing each POI and the subsequent area and ARF category applied for the design event modelling.

Table 3-2 ARF classification table

RFD Naming Convention	Area Range (lower to upper bounds)	Applied Area (Storm Injector)	Temporal Pattern Applied
ARFa	0km^2 to 1.5km^2	None, ARF = 1	Point
ARFb	1km^2 to 5km^2	2.5km^2	Point
ARFc	5km^2 to 15km2	10km^2	Point
ARFd	15km^2 to 35km^2	25km^2	Point
ARFe	35km^2 to 75km^2	50km^2	Point
ARFf	75km^2 to 140km^2	100km^2	Areal 100km^2
ARFg	140km^2 to 210km^2	175km^2	Areal 200km^2
ARFh	210km^2 to 300km^2	250km^2	Areal 200km^2
ARFi	300km^2 to 475km^2	400km^2	Areal 500km^2
ARFj	475km^2 to 700km^2	575km^2	Areal 500km^2
ARFk	700km^2 to 1000km^2	850km^2	Areal 1000km^2

3.3.5 Preburst Application

Preburst has been applied by injecting it prior to the storm. Pre-burst rainfall was applied following the methodology in the Stage 1 guidance, with the exception of using the GSDM pattern in lieu of Jordan's pattern. This alteration in temporal pattern was to ensure preburst rainfall was not significantly affecting peak flow. Table 3-3 presents the temporal patterns as applied in Storm Injector software.

Table 3-3 Preburst temporal pattern

Temporal Pattern	Duration (min)	Applicable burst durations (min)	Applicable AEPs
GSDM	60	15 | 20 | 25 | 30 | 45 | 60	All
GSDM	120	90 | 120	All
GSDM	240	180 | 270 | 360 | 540 | 720 | 1080 | 1440 | 1800 | 2160	All

3.3.6 Future Climate

An increase of 20% in rainfall intensity was applied to take into account the RCP8.5 scenario for 2090. The future climate modelling also incorporates ultimate landuse data discussed in Section 3.3.2 and consideration of sea level rise as discussed in Section 4.3.1.

3.3.7 Design Event Rainfall Losses

Without any stream gauge records to undertake a comprehensive Flood Frequency Analysis (FFA) or consider a wide range of calibration events, rainfall losses adopted for the design event modelling are based on the ARR Datahub i.e. 22 mm Initial Loss and 2.6 mm/hr Continuing Loss. This approach is consistent with neighbouring RFD catchments.

3.4 TUFLOW Hydraulic Model Update

To assess the hydraulic characteristics for the Bribie Island catchment, a detailed 1D/2D TUFLOW model has been developed by updating the previous hydraulic model (RFD, 2014). The TUFLOW hydraulic model was developed based on the TUFLOW software version 2020-10-AD-iSP-w64 which incorporates the Highly Parallelised Compute (HPC) solution scheme and represented the latest software version release at the time of project commissioning.

The Bribie Island model area is characterised by a combination of high-density urban areas and canal systems with tidal influences. Furthermore, there is no major river within the Bribie Island model domain with several individual tributaries draining north, south and east to Moreton Bay. The tributaries are characterised by a combination of complex trunk drainage systems and either natural or concrete lined open channels.

WT has undertaken significant updates and improvements to the previous hydraulic model (RFD, 2014) based on the latest available data. The improvements have been guided by Stage 1 and 3 of the RFD process and ongoing discussions with Council. The key improvements to the model are summarised as follows:

- Adoption of TUFLOW build 2020-10-AD for model development and validation.
- HPC scheme has run times less than 1 hour for a 4 hour model simulation.
- Maintained fixed 5m grid with updated 2019 LiDAR.
- Refinement of roughness layers and adoption of depth-varying roughness to represent flooding more accurately in the catchment.
- Significant updates to the previously adopted 1D network files and inclusion of recently constructed structures.
- Updates of 2D structures.
- Inclusion of more refined inflows and expansion of the hydraulic model extent to capture flooding in more of the catchment.

3.4.1 Model Layout and Extents

The TUFLOW model code boundary covers most of the Bribie Island area. The code boundary extent has been modified only slightly from the previous study mainly to remove some glass walling affects. Figure 3-2 shows the TUFLOW model code boundary for both the previous and current study with additional trunk drainage networks also shown. The previously adopted RFD model grid orientation of north-south, with no orientation angle has been maintained.

3.4.2 Model Topography

The model base topography is represented using 1.0 m resolution 2019 LiDAR data supplied by MBRC. Currently the model reads the latest survey over the previous 2014 TUFLOW model topography and subsequently supersedes the previous values where new data is available. There were several other localised DEMs provided by MBRC, representing as constructed earthworks completed after the capture of the 2019 LiDAR, which have been incorporated into the TUFLOW model as part of the modelling update.

Topographic modifications such as weirs and the filling of road embankments were maintained from the previous model where appropriate. Several new topographic amendments have been incorporated, specifically ridge lines have been added in key overtopping locations. Gully lines along creek channels were updated with the latest 2019 topography where lower than previously enforced gully line values.

Observations from the site visit noted challenges in modelling several small urban channels throughout the Bribie Island region using a 5m fixed grid. Figure 3-1 presents some typical channels and overland flow paths observed throughout the catchment which range from 4 to 10 metres wide. To represent this in the model a thin gully line has been applied to ensure conveyance is not overestimated through the use of a 5m wide z shape. This limitation of the TUFLOW model as configured has been highlighted to understand the limitations of the adopted cell size in urbanised catchments. Potential solutions MBRC could consider in future Bribie Island RFD revisions would be a finer grid cell size or application of Sub-Grid Sampling (SGS).

Figure 3-1 Open channel and overland flow path near Indra Ave observed on site visit, 7th March 2022

Figure 3-2 Hydraulic model extent change

3.4.3 Floodplain Structures

3.4.3.1 Bridge Structures

A full and detailed review of all bridge structures and associated model parameters and representation has been undertaken. The key alteration from the previous study is that calculation of losses for 2d_lfcsh is set to ***Portion*** compared to the previous ***Cumulate***. On review of the previous adopted values in the 2d_lfcsh layers it was noted the model was overestimating form losses through structures in layer 1 as values applied had not been divided by the length of the bridge in the flow direction. Furthermore, layer 2 did not have any form loss applied. This update has adopted a value of 1.6 through the structures deck. The previous model incorporated several layered flow constrictions which model complex archway culverts. These layers have been checked and have remained in this iteration of the model. No changes were required.

3.4.3.2 Stormwater Pipes and Culverts

MBRC’s supplied GIS layer of stormwater and culvert pipes was used for the previous RFD modelling. These stormwater pipes and culverts have been reviewed and updated as part of this study. Numerous erroneous pipe details (adverse grades) and missing pipes have been updated to better reflect current catchment conditions.

Significant discussion on the modelling of 1D network pits was undertaken with MBRC. For Bribie Island the default pit (with no consideration of upstream pits) is modelled as a Q type pit linked with an unlimited capacity inlet curve in line with MBRCs approach to assume that pipe capacity governs the stormwater network capacity.

The MBRC GIS database for the stormwater network included a significant number of erroneous data points with missing and incorrect invert levels. For the purposes of the TUFLOW modelling, missing or incorrect invert levels were estimated by using the closest available correct invert level and using the LiDAR DEM to estimate a slope. Comments have been provided in the 1D network file where appropriate to document where estimates have been adopted. Figure 3-5 illustrates the stormwater pipes and culverts included in the updated hydraulic model.

3.4.3.3 Other Structures

There were no fauna fences requiring modelling within the Bribie catchment as per the provided GIS files.

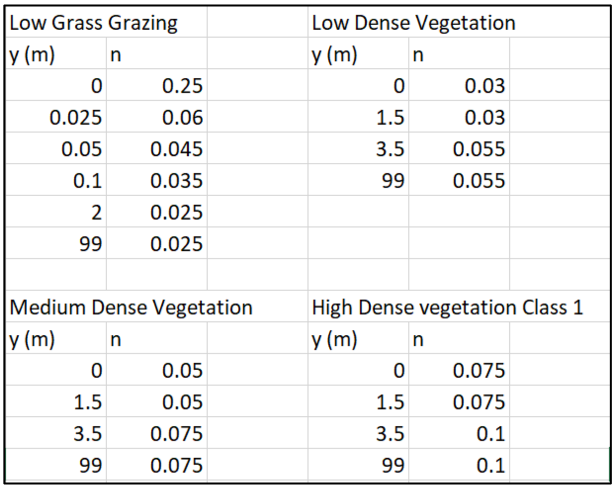
The guardrail located at the Cotterill Avenue has been modelled with all other guardrails in the region being outside of the 2014 PMF flood extents. The Cotterill Avenue guardrail has been modelled as per the TMR hydrologic and hydraulic guidelines (2019) as a 2d_lfcsh line layer. An assumption of a 300 mm depth to the underside of the W beam and a 350mm depth of cross-member has been assumed without the specific guardrail drawings available.

3.4.4 Floodplain Roughness

The floodplain roughness spatial delineation rasters and vector GIS files were provided by MBRC (2019) for use in the updated TUFLOW model. The roughness delineation was based on machine learning techniques, as outlined in the Stage 2 Report. The 2019 datasets are raster based and significantly refined compared to the 2014 data (vector datasets). Table 3-1 presents the adopted roughness values for the respective delineated areas and Figure 3-3 shows the adopted depth varying roughness values. These values were determined through the calibration process of several other catchments in the MBRC region and further validated to comparison of debris marks for two historical flood events in this catchment. Figure 3-4 illustrates the spatial variation in roughness applied in the hydraulic model.

Table 3-4 TUFLOW materials roughness values

Material ID	Manning’s n	Description
1	Low Grass Grazing.csv	Open Space (grasses)
2	Low Dense Vegetation.csv	Low Density Understory – Vegetation
3	Medium Dense Vegetation.csv	Medium Density Understory – Vegetation
4	High Dense Vegetation_Class1.csv	High Density Understory – Vegetation
5	0.04	Open Space – Mangroves (Marsh)
6	0.08	Low Density Understory – Mangroves
7	0.10	Medium Density Understory – Mangroves
8	0.17	High Density Understory – Mangroves
13	0.015	Roads
14	0.015	Concrete
15	0.03	Waterbody
16	0.5	Buildings
19	0.025	Facilities



Low Grass Grazing		Low Dense Vegetation	
y (m)	n	y (m)	n
0	0.25	0	0.03
0.025	0.06	1.5	0.03
0.05	0.045	3.5	0.055
0.1	0.035	99	0.055
2	0.025		
99	0.025		
Medium Dense Vegetation		High Dense vegetation Class 1	
y (m)	n	y (m)	n
0	0.05	0	0.075
1.5	0.05	1.5	0.075
3.5	0.075	3.5	0.1
99	0.075	99	0.1

Figure 3-3 Depth varying Manning’s values

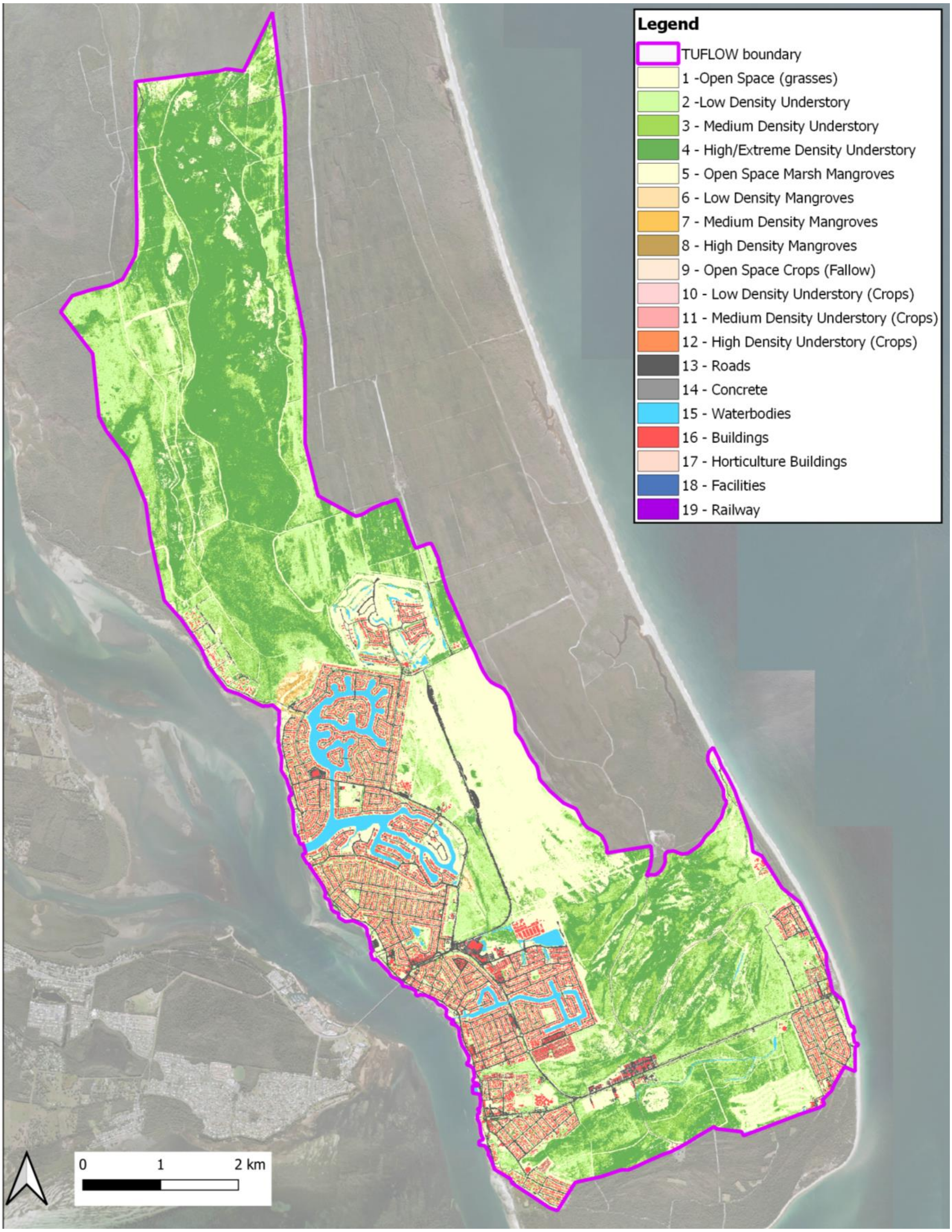


Figure 3-4 Hydraulic model roughness layout

3.4.5 Inflow Boundaries

Model inflows polygons were initially based on the subcatchment breakdown in the provided WBNM Model from Stage 2. The inflows have been represented in the hydraulic model as a series of local catchment Source Area ("SA") polygon inflow boundaries which are shown in Figure 3-5. The SA polygons are distributed to 1D pit nodes where the trunk drainage is the main flow path through the catchment. For catchments where a clear creek or channel is the main conveyance a standard SA polygon is applied in which flow is initially distributed to the lowest elevation cell and then distributed proportioned by depth thereafter. There are no total inflows applied in the hydraulic model. Therefore, the routing is undertaken within the hydraulic model. The routing will be replicated in the WBNM hydrological model through a joint calibration process discussed in Section 5.

Initially the subcatchment boundary polygon was applied as the SA boundary although it is acknowledged that there are limitations with this approach in complex urban environments where there can be multiple flowpaths and the trunk drainage can have a different flow direction to the terrain. To address these complexities several subcatchment inflow locations were either split or enforced to cells at the outlet. For the splitting of subcatchments, the flow was proportioned by estimated catchment area weighting. This process can involve splitting flow between trunk and creek 2D cells within a single catchment respectively. In the scenario where a subcatchment was subject to significant break out flows from an unconnected neighbouring catchment, the outlet cells were enforced as the inflow boundary to ensure the local inflows were not applied at inappropriate locations with the proportional depth distribution method.

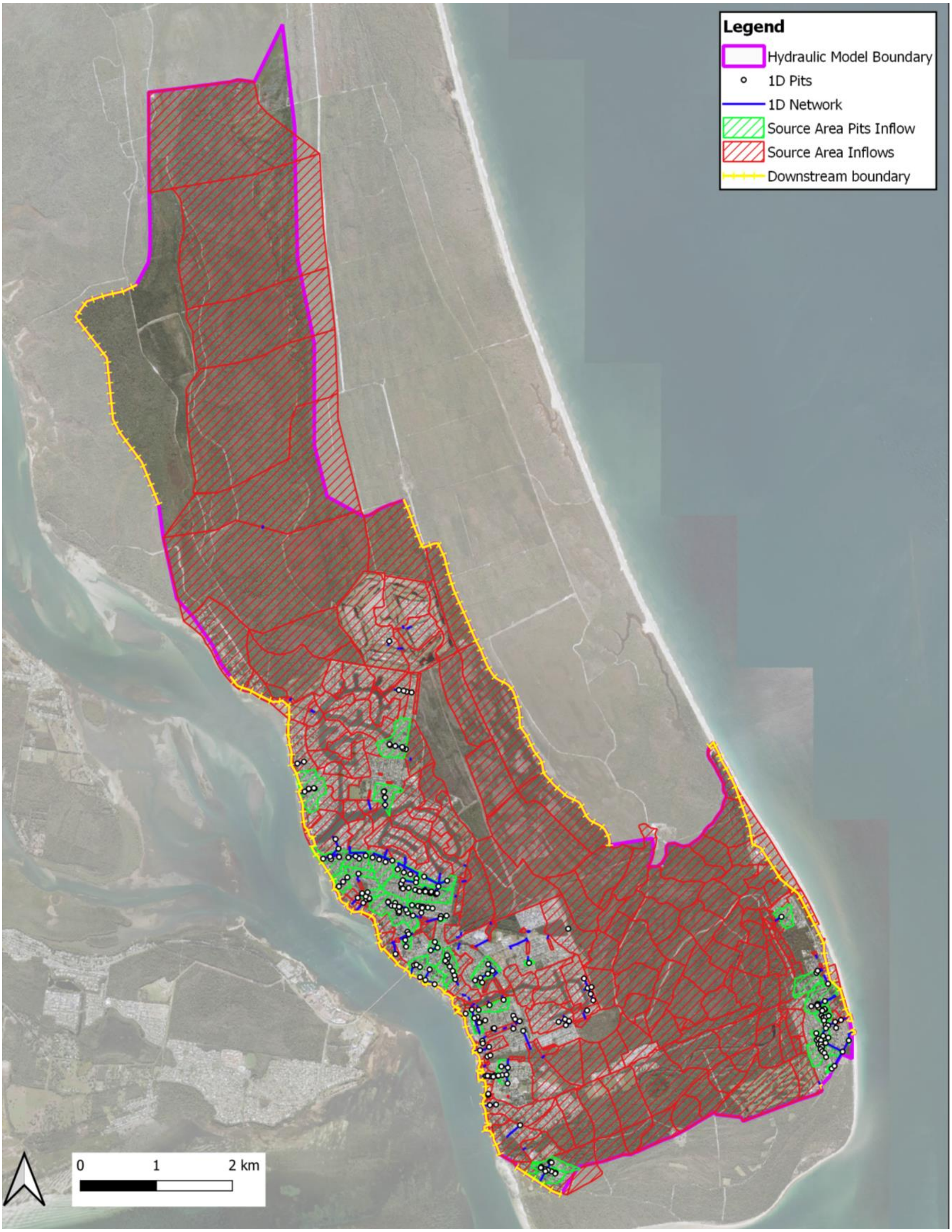


Figure 3-5 Hydraulic model trunk network and inflow boundaries

4 MODEL METHODOLOGY AND SIMULATIONS

4.1 Validation to Historical Events

There are no available stream gauges within the Bribie Island Catchment, although there is relatively good rainfall coverage with 2 gauges within the wider catchment. As such, only debris marks were able to be considered for model validation. Table 4-1 outlines the flood events considered for the model validation. Appendix A presents a description of the rainfall for each event and how the rainfall was applied to the WBNM model.

Table 4-1 Validation event summary

Event	# of Debris Marks in TUFLOW model extent	WBNM Start time	WBNM End Time
February 2022	30	23/02/2022 06:00 AM	28/02/2022 12:00 AM

4.1.1 Rainfall Data Available

MBRC supplied historical rainfall data at all rain gauge stations surrounding the respective catchments. Table 4-2 summarises the available data for the respective events and study catchments. Rainfall data was extracted for individual events by Council and provided in CSV format.

Table 4-2 Rainfall Gauges Used for Validation

Gauge Name	ID	Event Availability
Bribie Island Alert	40978	Feb2022
Banksia Beach Alert	540735	Feb2022

4.1.2 Stream Gauge Data Available

There are no stream gauges available in the Bribie Island Catchment.

4.1.3 Flood Debris Marks Available

Debris marks left by flood water or other markings, such as painted lines, are referred to as flood marks and provide an estimate of where peak flood levels extended within the floodplain. Flood debris marks for the respective events were made available and are based on surveyed levels at each location. These flood marks have been used to validate the peak water levels simulated in the TUFLOW hydraulic model.

It is noted that these levels are subject to uncertainty as debris may get lodged at lower than maximum flood levels. Hydro-dynamic forces on structures may also result in higher water levels at the structure than in the open floodplain. Table 4-3 summarises the number of debris marks available for the validation event. It is noted that some debris marks were captured outside of the modelled flood extent and are most likely attributed to small overland flow paths rather than the intent of the model which is flooding from creeks and major overland flow paths.

Table 4-3 Debris mark availability summary

Event	# of Debris Marks	# of Debris Marks in TUFLOW model extent
February 2022	40	30

4.1.4 Tidal Levels

A tidal boundary for the Bribie Island model domain was artificially created for the February 2022 event through use of the Beachmere Alert station (540740) gauge record. The tidal sinusoidal wave recorded before the flood wave affected levels at the gauge was repeated across the entire duration of the rainfall event. Figure 4-1 presents the estimated tidal levels in the absence of any recorded tidal levels adjacent to the Bribie Island areas.

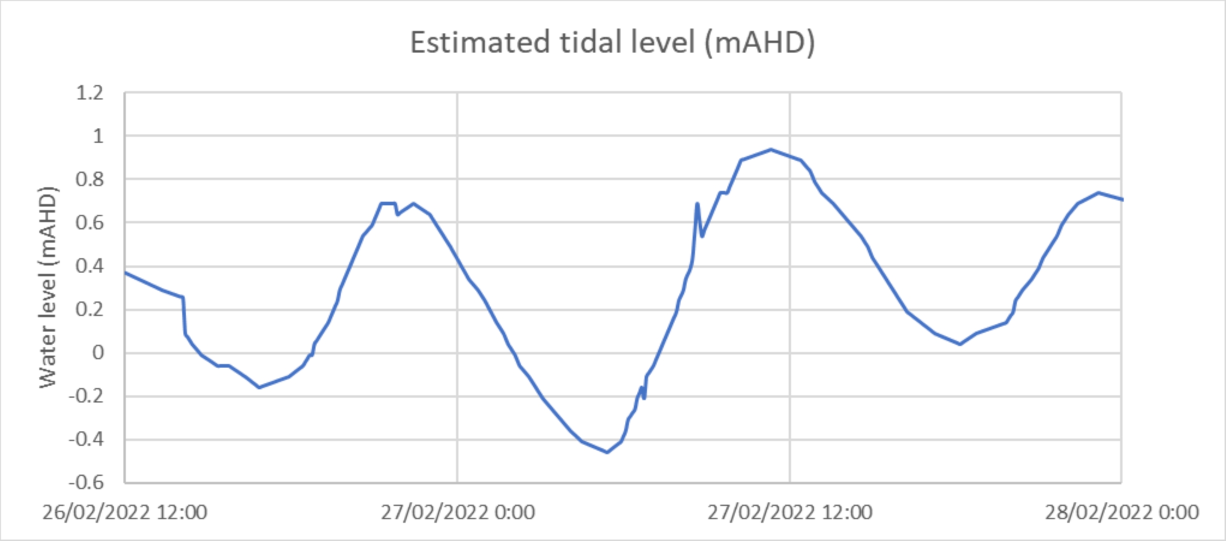


Figure 4-1 **Estimated dynamic tailwater level applied to February 2022 Validation event**

4.1.5 Losses and Catchment Parameters

Table 4-4 presents the adopted Initial and Continuing Loss values for the validation event across the Bribie Island catchment. A continuing loss value of 2.5 mm/hr was found to be appropriate based on the hydraulic model validation results and is consistent with other catchments throughout the MBRC region which are calibrated to more reliable stream gauge data. It is noted that there is the proposition that Bribie Island could be subject to higher loss values as its geology is predominantly sand although there is insufficient data to override the standard ARR19 values.

Table 4-4 **Validation events – WBNM adopted parameters**

Catchment	Event	Catchment Lag Parameter	Initial Loss (mm)	Continuing Loss (mm/hr)
Bribie Island	2022	1.6	20	2.5

4.2 Hydraulic Equivalent Hydrologic (HEH) Model development

4.2.1 Points of Interest

Figure 4-2 presents the Points of Interest (POIs) adopted for the Bribie Island catchment. There are 23 POIs in total across the catchment. The following comments are noted outlining the decision-making process applied in selecting these locations:

- There are 13 POIs in total across the catchment.
- POIs have focused on the following locations (in this order of priority):

- Proximity to key flood evacuation roads – not as critical for Bribie Island with the main access road over Pumicestone Passage.
- Inflow locations to canal systems (Dux Creek).
- Obtaining a spread of ARFs throughout the catchment – this also involved selecting “typical” Bribie Island catchments. It was noted there are several small Moreton Bay draining catchments which have similar catchment features (landuse, area etc). Therefore, only one (1) of these catchments was selected noting that the critical duration and ARF will be applicable to similar catchments.

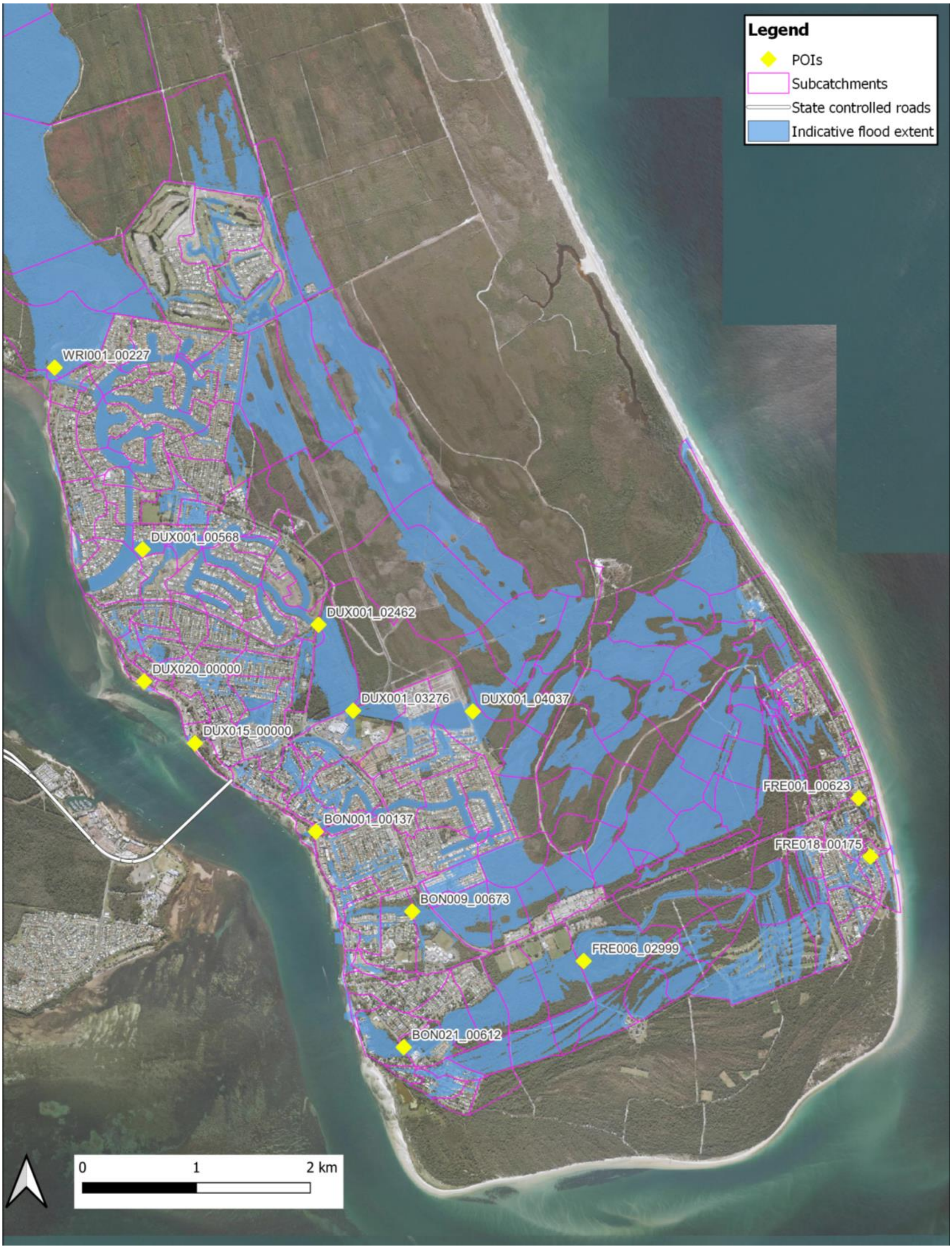


Figure 4-2 Bribie Island Point of Interest locations

4.2.2 Methodology

The methodology adopted to develop the HEH model for Bribie Island has been based on the technical note provided by BMT titled “Final HEH Modelling Methodology” dated 22 August 2022 (see Appendix E). A summary of the modelling process undertaken for the Bribie Island catchment is provided below:

- Simulated 3 different design flood events – 10%, 1% and 0.05% Annual Exceedance Probability (AEP). For each event both the 180-minute and 1440-minute storms were simulated. The ARR1987 temporal patterns and IFDs were utilised. The durations were selected based on the dominant critical durations determined in the previous 2012 RFD Bribie Island flood study.
- For each POI a comparison of hydraulic (TUFLOW) and hydrologic (WBNM) models was undertaken. The criteria to determine a successful match of the models was:
    - Peak flows within 10%.
    - Timing of the peak flow within 15 minutes of each other.
    - The Nash Sutcliffe Efficiency (NSE) score was also output for information purposes.
- The initial approach to achieve joint calibration at the POI was to alter the stream routing parameters within the WBNM model.
- For locations where stream routing alterations alone were unable to achieve a hydrograph match and the hydraulic model suggested there was significant upstream storage within the catchment, artificial storage was added to the WBNM model. Artificial storage was added through Storage – Discharge (SQ) curves generated by comparing WBNM “inflows” and TUFLOW “outflows” for each event as outlined in the technical note. An average of the SQ curves was taken from the 6 events modelled and applied in the WBNM model at the relevant location.

It is important to note that the HEH methodology was developed considering large floodplains and natural waterway systems. The Bribie Island catchment is unique in that it is has flat undulating terrain prone to ponding in the upper catchments and canal systems throughout the urbanised areas in the downstream areas. For these reasons the methodology has limitations in its application throughout the catchment and the criteria has not been able to be met for all events at each POI despite significant model testing and iteration.

4.3 TUFLOW Hydraulic Model

4.3.1 Adopted Design Tailwater Conditions

A static tailwater of 0.77 mAHD was applied to current climate design event modelling. An increase of 0.8 metres was applied to future climate modelling to consider the oceanic/tidal RCP8.5 2090 conditions.

4.3.2 Design Event Structure Blockage

The Stage 1 project developed a methodology for calculating blockage for bridge and culvert structures in alignment with ARR 2019 guidance. Blockages are to be represented for the three different AEP ranges (less than 5% AEP, greater than 0.5% AEP, and in-between these two events) using different 1D network and layered flow constriction files. Within each 1D network file for the ARR 2019 blockage case, each culvert has either a pBlockage (for reduced area method or inlet control culverts) or an increased inlet loss (for modified energy loss method approach). Bridge layered flow constriction files have inlet blockage modelled within L1 pBlock. Table 7-2 presents the representative blockage values where an L10 of 1.5 metres was adopted for the urbanised Bribie Island catchment as per Stage 1 guidance. The values considered both inlet blockage and barrel blockage from sedimentation.

Table 4-5 Blockage matrix

ARI	W < L_{10}	$L_{10} \leq W \leq 3*L_{10}$	W > $3*L_{10}$
50% to 10%	25%	0%	0%
5% to 0.5%	50%	15%	0
0.2% to PMF	100%	25%	10%

4.3.3 Model Simulations

4.3.3.1 Existing Climate Simulations

The 20%, 10%, 5%, 2%, 1%, 0.1% and 0.05% AEP design events have been simulated in the TUFLOW model for both unblocked (E00) and blocked (E02) scenarios. An enveloped grid surface (E03) was created for both the blocked/unblocked scenarios.

4.3.3.2 Future Climate Simulations

5%, 2%, 1%, 0.1% and 0.05% AEP design events were simulated with future climate conditions including increased rainfall intensity (20%), ultimate landuse and increased tailwater levels (+0.8m). The same storms selected for the current climate were modelled for future climate scenarios.

5 MODEL RESULTS AND OUTCOMES

5.1 TUFLOW Hydraulic Model Validation

5.1.1 February 2022

Figure 5-1 presents spatial map of the hydraulic model validation results when comparing the TUFLOW model results to the surveyed flood depths for the February 2022 flood event. Appendix A provides the histogram distribution of the differences. Overall, the hydraulic model has performed reasonably well in matching the observed flood marks. Approximately 17% of the markers were within 100 mm and approximately 66% of the modelled depths were within 300 mm of the measured levels. Considering the uncertainty of the hydrologic modelling without any stream gauge calibration these results are encouraging and suggest the adoption of the parameters for the hydrologic and hydraulic model is valid.

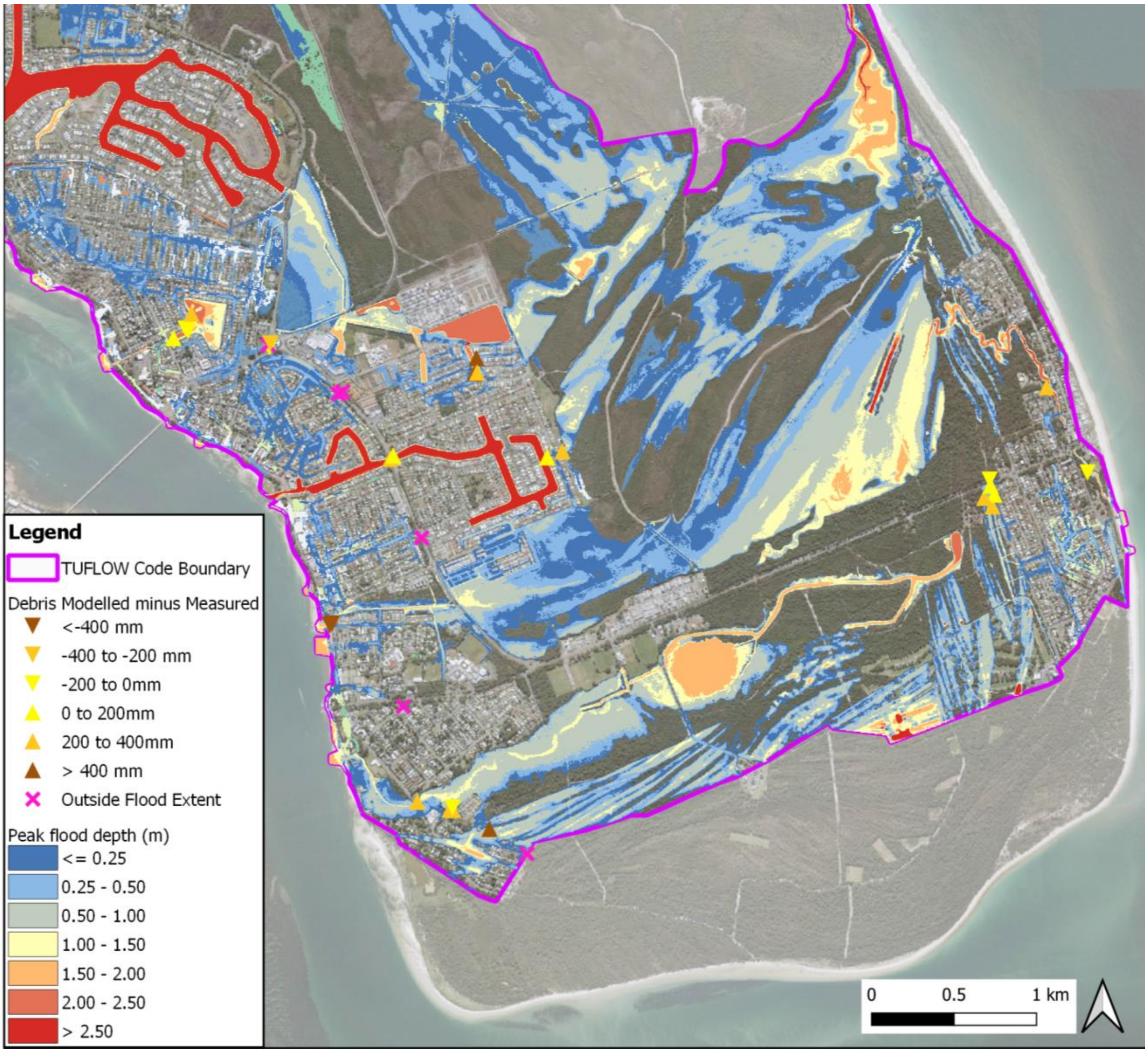


Figure 5-1 Bribie Island February 2022 – extent and debris locations

5.2 WBNM Hydraulic Equivalent Hydrologic Model performance

Appendix C provides a tabular description of the results and plots/statistic tables for each simulated event/duration at each POI. The HEH modelling was undertaken to add confidence that the Bribie Island WBNM model is representing the catchments hydraulic response (where possible) through alteration of stream routing parameters and the addition of artificial storage curves. All the 12 POI locations required artificial storage curves added into the WBNM model.

Because of the reasons discussed previously, none of the locations have met the HEH criteria for all the simulated events. For each POI, justification has been provided with a description of the complex hydraulics unable to be modelled in the simplistic WBNM runoff routing model. Despite the limitations, the addition of storage curves has significantly improved the match of the hydrologic and hydraulic models with increased confidence that the HEH model is suitable for guiding critical durations and temporal patterns at the POIs. With the increased uncertainty of the HEH model, additional hydraulic simulations were undertaken.

Overall, significant model testing and iterations have been undertaken and it is anticipated that any further improvement in the HEH model is restricted by the challenging hydraulic characteristics of the catchment. Based on this and the encouraging results achieved given the challenges of the catchment, the Bribie Island HEH model is suitable to inform design event storm selection with additional hydraulic model simulations to account for the uncertainties documented herein.

5.2.1 Critical Storm Selection

Table 5-1 presents the selected storm events simulated in the TUFLOW model. Following on from Stage 1 guidance the following process was undertaken for the design event selection. The storms were selected using the HEH model and the process was undertaken for each ARF category (within Storm Injector software).

1. Design storms generated with relevant ARF applied.
2. Storms with embedded bursts where smoothing was over 40% were removed from the analysis.
3. WBNM HEH model simulated for all design storms.
4. Critical storms and peak flows extracted for corresponding POIs in ARF category.

From this analysis there were approximately 10 critical storms across the POIs from the WBNM modelling for each AEP. To reduce the number of hydraulic simulations, a process was undertaken to optimise the selected storms for hydraulic simulation. This process involved comparing the WBNM HEH peak flow from a subset of 5 storms to the actual critical peak flow (from all storms) across all POIs. All possible combinations of critical storms were tested, and the optimal subset of storms was selected for each AEP based on the mean and minimisation of outlier flow differences. In general, this over or underestimation was aimed to be under +-10%.

Table 5-2 presents the difference in peak flow (HEH WBNM modelling) from the maximum of the selected events versus the peak flow from simulating all temporal patterns and durations showing that differences are less than 10%. The source grids of the envelope results were also analysed hydraulically, and these did not identify any single storm event which dominated the envelope grids across the AEPs.

Table 5-1 Critical events selected

Event	Simulated events
20%	120minTP07_ARFa, 360minTP09_ARFa, 60minTP07_ARFa, 1440minTP04_ARFc, 540minTP05_ARFb
10%	120minTP06_ARFa, 360minTP10_ARFa, 45minTP06_ARFa, 1800minTP06_ARFc, 540minTP01_ARFb
5%	180minTP08_ARFa, 360minTP05_ARFa, 45minTP06_ARFa, 1800minTP10_ARFc, 540minTP01_ARFb
2%	120minTP03_ARFa 30minTP01_ARFa 360minTP10_ARFa 2160minTP09_ARFc, 540minTP06_ARFb
1%	120minTP03_ARFa 30minTP01_ARFa 360minTP02_ARFa 2160minTP04_ARFc, 540minTP06_ARFb
1 in 1000	180minTP07_ARFa. 30minTP08_ARFa. 360minTP03_ARFa. 2160minTP03_ARFc, 720minTP03_ARFb
1 in 2000	180minTP07_ARFa, 30minTP08_ARFa, 360minTP05_ARFa, 2160minTP01_ARFc,720minTP03_ARFb

Table 5-2 1% AEP peak flow over/underestimation at POIs

POI	Peak flow difference with selected storms (% difference to all storms critical flow)		
	5% AEP	1% AEP	0.01% AEP
DUX015_00000	0%	0%	-7%
DUX020_00000	0%	-3%	-1%
DUX001_02462	7%	1%	-1%
DUX001_00568	8%	1%	5%
DUX001_04479	0%	4%	8%
FRE006_02999	0%	0%	0%
BON021_00612	2%	0%	3%
BON009_00673	0%	-1%	0%
BON001_00137	2%	-1%	0%
FRE001_00623	-1%	0%	0%
DUX001_03276	6%	6%	0%
FRE018_00175	-1%	0%	0%

5.3 Design Flood Behaviour

5.3.1.1 Peak Flow Comparison

To confirm the HEH performance a comparison of the WBNM peak flow and TUFLOW peak flow was undertaken at each POI. Table 5-3 presents the comparison for the 1% AEP event. The results show reasonable correlation between the models with similar peak flows and similar critical storms giving further confidence that the HEH WBNM model is suitable to be utilised for the selection of critical storms.

Table 5-3 1% AEP WBNM vs TUFLOW peak flow comparison

POI	WBNM Duration (min)	WBNM Adopted TP	WBNM Peak flow	TUFLOW Duration (min)	TUFLOW Adopted TP	TUFLOW Peak flow
WRI001_00227	720	TP03	55.9	2160	TP04	67.9
FRE018_00175	120	TP03	3.9	120	TP03	3.8
FRE006_02999	30	TP01	11.9	360	TP02	8.9
FRE001_00623	2160	TP04	3.6	2160	TP04	3.8
DUX020_00000	180	TP01	2.8	30	TP01	2.2
DUX015_00000	120	TP03	10.1	30	TP01	5.9
DUX001_04479	720	TP03	29.5	360	TP02	24.3
DUX001_03276	720	TP03	27.4	360	TP02	30.5
DUX001_02462	2160	TP06	31.4	360	TP02	31.3
DUX001_00568	120	TP06	69.9	30	TP01	81.2
BON021_00612	360	TP02	8.1	360	TP02	11.1
BON009_00673	360	TP10	6.7	360	TP02	8.8
BON001_00137	270	TP07	27.2	360	TP02	25.3

5.3.1.2 Comparison to RFD 2014

Figure 5-2 presents the difference in peak flood level between the RFD 2022 (this study) and the previous RFD 2014 peak flood level across the catchment for the 1% AEP event (both unblocked scenarios). In general, there is no consistent pattern of either increasing or decreasing flood levels with a wide range of differences. Peak flood levels are generally within 300 mm of previous results. The changes are most likely attributed to the change in hydrologic guidelines i.e. ARR 2019 and revised design rainfall intensities, and also revised Manning's n delineation and values. This study has significantly increased the modelled flood extent with more flow paths modelled hydraulically along with more refined subcatchment inflow locations.

A similar comparison has been undertaken for the Design Flood Event (DFE) which for this major update is the enveloped future climate 1% AEP scenario. Figure 5-3 presents a comparison of flood levels of the 2022 RFD DFE to the RFD 2014 DFE which was based of the Median Duration Storm (MDS). Similarly, flood levels have increased significantly and likewise decreased significantly throughout the catchment. Flood levels in Dux Creek have generally increased significantly by up to 500 mm.

A comparison of the blocked and unblocked scenarios showed that blockage increased flood levels up to 100 mm at key structures throughout the catchment. The catchment is not overly sensitive to blockage due to its urbanised nature and predominantly trunk network system rather than transverse culverts.

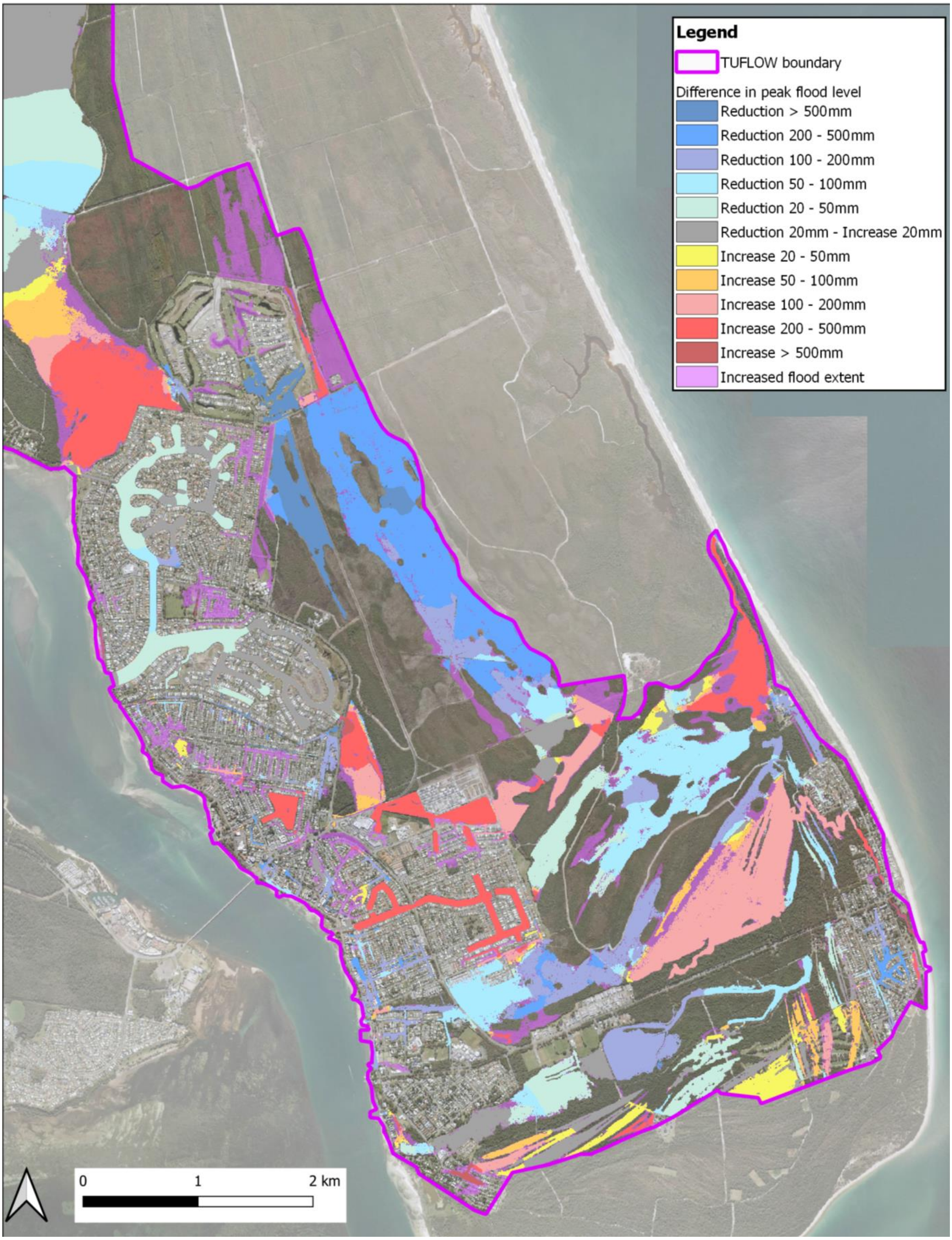


Figure 5-2 RFD 2022 minus RFD 2014 1% AEP peak flood level (unblocked)

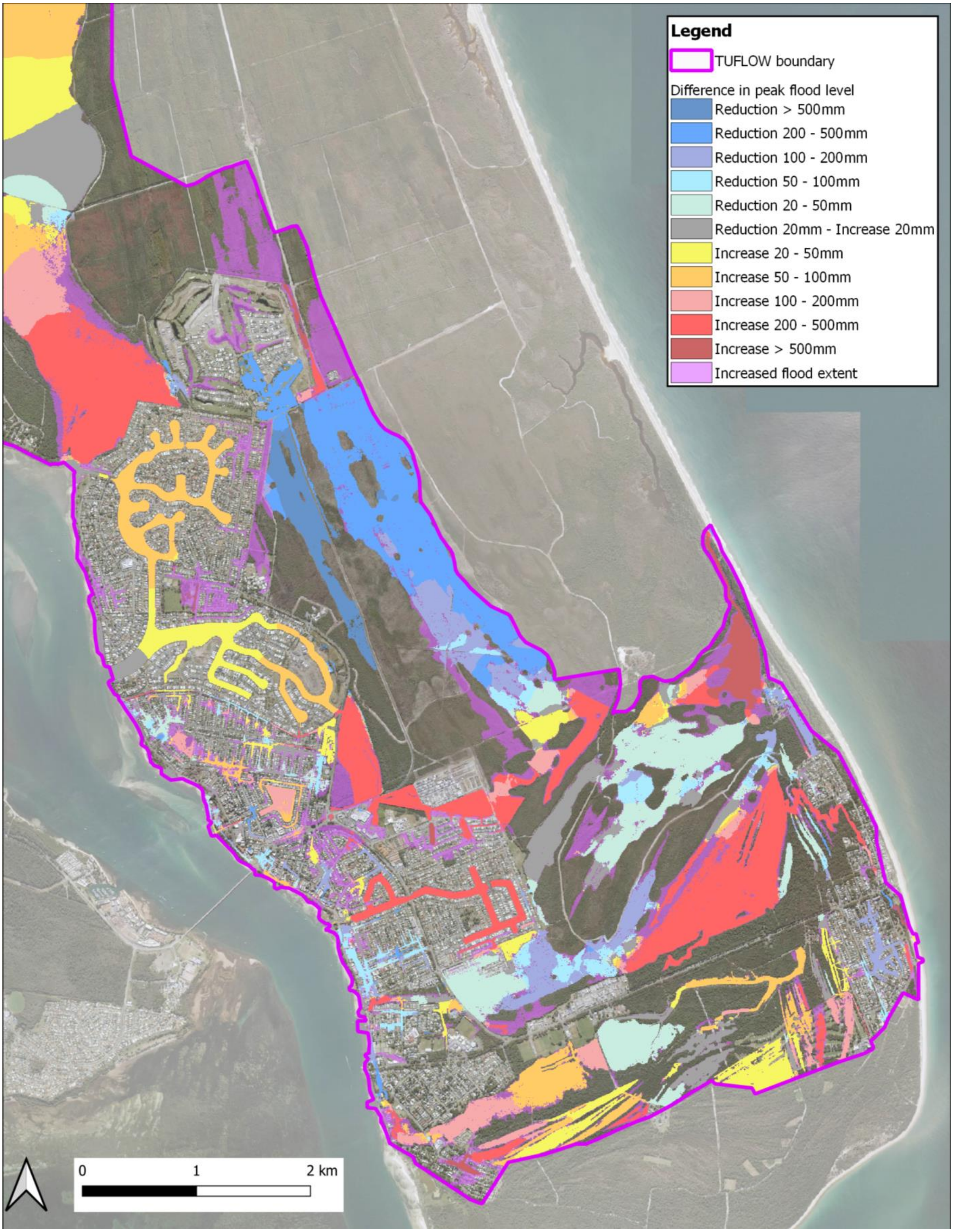


Figure 5-3 RFD 2022 minus RFD 2014 1% AEP DFE peak flood level (future climate)

5.4 Model Limitations and Quality

The model performs reasonably well with very low Mass Error (ME) of 0.01%. Furthermore, the minimum dt value observed in the hpc tlf file is reasonable with a value of 0.6 which is approximately 1/10th of the cell size (see Figure 5-4). Overall, the 1D network results are encouraging with smooth hydrographs and no erroneous velocities observed. The model health will constantly be assessed in the upcoming stages as the model will be tested across a wider range of storm magnitudes and durations.

Watercourses within the Bribie Island catchments were represented in the 2D domain, for which the grid resolution is limited to 5 m. This may not allow adequate representation of the channel conveyance, particularly for smaller, more frequent flood events. In some instances, this limitation may lead to the model over or underestimating conveyance in the watercourses. The extent of this over or underestimation will vary according to local topographic factors.

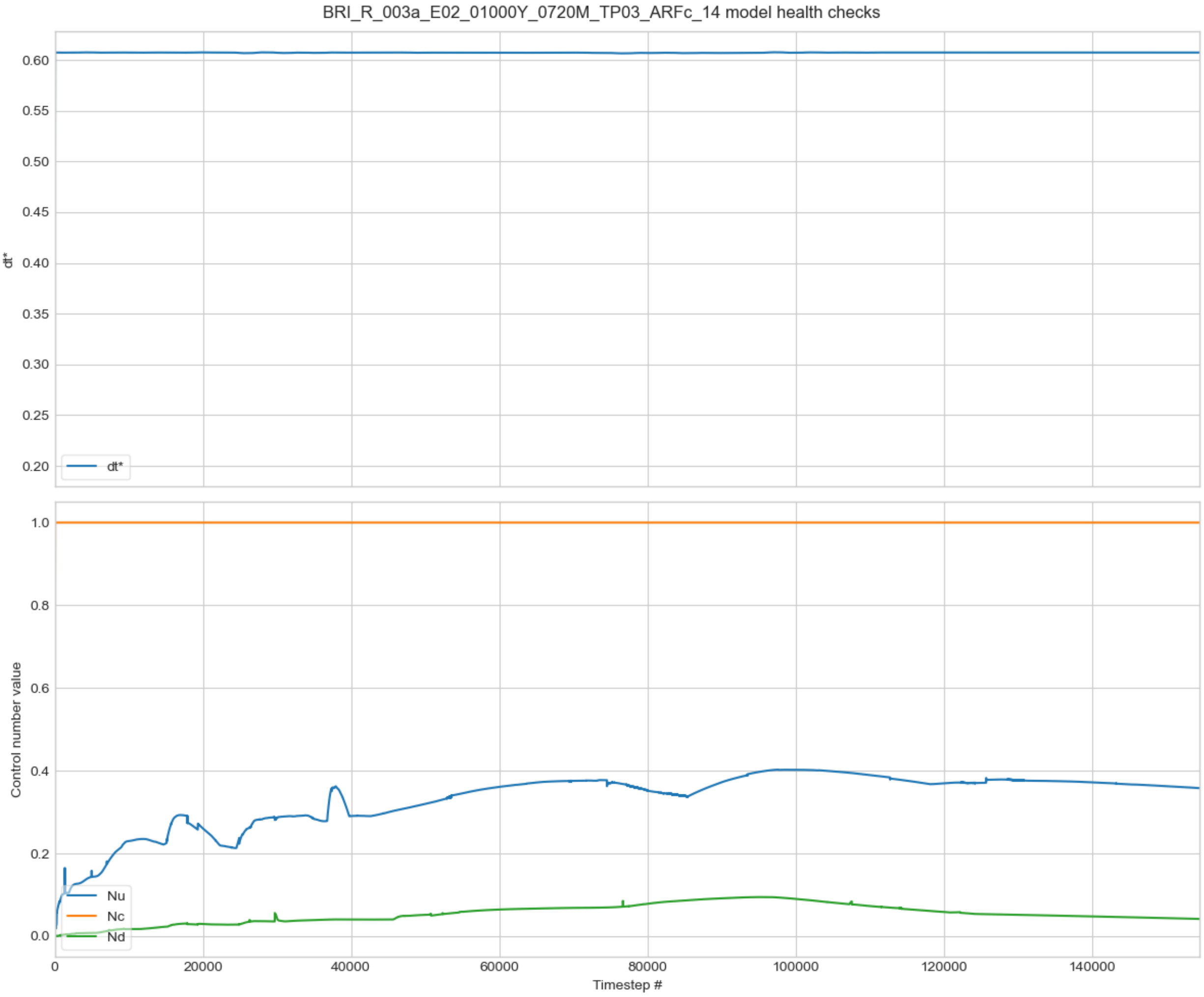


Figure 5-4 TUFLOW model health check

5.5 Model Specification and Run Times

Bribie Island is one of the smaller catchments within the MBRC RFD study area, encompassing 49.2 km^2 and 8,467,649 grid cells (at 5m cell size). Table 5-4 provides a summary of the Bribie Island TUFLOW model specification and run times. It is noted that runtimes will vary depending on CPU and GPU hardware used.

Table 5-4 Bribie Island model specification and run times

Event	Model run time (hours) (varies per duration)	Startup Memory (MB)	GPU memory required (MB)
20% AEP (360min)	0.75	3500	1800
1% AEP (360min)	1.2		
1 in 2000 AEP (360min)	1.5		

6 CONCLUSION

As part of the Stage 4 and 5 update of the RFD for Bribie Island, a provided WBNM hydrologic model (as part of the Stage 2 study) and an existing TUFLOW hydraulic model were updated according to the latest industry guidance (ARR 2019). The models were specifically set up in accordance with the requirements outlined by the Moreton Bay Regional Council (MBRC) for the Regional Flood Database (RFD) project. The aim was to ensure a consistent approach across the entire Local Government Area (LGA) and facilitate the integration of the model and its outputs into MBRC's database.

The primary objective of the project was to deliver the TUFLOW model and its associated outputs in a digital format. Therefore, this report presents only a selected subset of the results obtained from the model. The focus was on providing the necessary information that can be readily integrated into the database and utilized for further analysis and management of flood risk in the Bribie Island catchment.

The outcomes of this work will serve as a valuable resource for future stages of the Regional Floodplain Database. The model and its outputs will contribute to a comprehensive understanding of flood behaviour in the Bribie Island catchment, aiding in the assessment and management of flood risk. The information obtained from the model will support informed decision-making processes related to floodplain management, land-use planning, and infrastructure development in the area. It will also be used in all MBRC public flood mapping products such as the Flood Check Reports and Moreton Bay Flood Viewer.

Overall, the development and delivery of the models for the Bribie Island catchment, adhering to the prescribed approach outlined by MBRC, provides a valuable foundation for future stages of the RFD. The digital format of the model and its outputs facilitates the integration of flood data into MBRC's database, supporting ongoing efforts to analyse and effectively manage flood risk in the area.

7 DISCUSSION

The hydrologic and hydraulic models developed as part of this update reflect the first validated models throughout the Bribie Island catchment representing a significant improvement over previous iterations. As outlined in this report, there are limitations in the adopted 5 m grid cell size in the hydraulic model to represent the smaller channels throughout the urbanised Bribie Island catchment when compared to the other floodplain catchments. It is recommended to reconsider this cell size in future iterations of the modelling. Other potential solutions MBRC could consider in future Bribie Island RFD revisions would be the application of Sub-Grid Sampling (SGS).

It is important to note that the models have only been validated to historical debris marks which have significant uncertainty. A stream gauge within the Bribie Island catchment would add significant value to future calibration/validation events and model iterations as it would allow matching of not only peak heights, but of hydrograph shapes throughout the catchment. This calibration to a stream gauge would give further confidence in model parameterisation and the resulting design flood level outputs. This is particularly relevant for Bribie Island where a stream gauge could improve understanding of appropriate rainfall loss values given its geology is predominantly sand and unlike any other neighbouring RFD catchment.

8 REFERENCES

1. Australian Rainfall and Runoff (ARR) (2019): A guide to flood estimation, Commonwealth of Australia (Geoscience Australia), 2016.
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9. Regional Flood Database - Stage 2 - Hydrography Landuse and Hydrology, AECOM, 2020
10. Regional Flood Database – Stage 3 Analysis Summary, Moreton Bay Regional Council, 2021

APPENDIX A
VALIDATION EVENT RAINFALL ASSESSMENT AND DEBRIS HISTROGRAMS

A-1 Rainfall Application

A-1-1 February 2022

Hydrological data from rainfall stations Bribie Island Alert and Banksia Beach Alert were utilised to generate the spatial distribution of rainfall in the February 2022 event. Figure A-1 and Figure A-2 present the cumulative and sub-daily rainfall plots for the Bribie Island Alert (40978) and Banksia Beach Alert (540735) rainfall stations respectively. Available information indicates that over 800 mm of rainfall occurred at both stations in the period 22 February to 4 March 2022. Hourly rainfall totals indicate that several storm events occurred during this period. The peak 1-hour bursts, which most of the flooding in the urbanised catchments would have been attributed to, occurred during the mid-morning of 27 February 2022. Figure A-3 presents the WBNM subcatchment spatial distribution of total rainfall for the event.

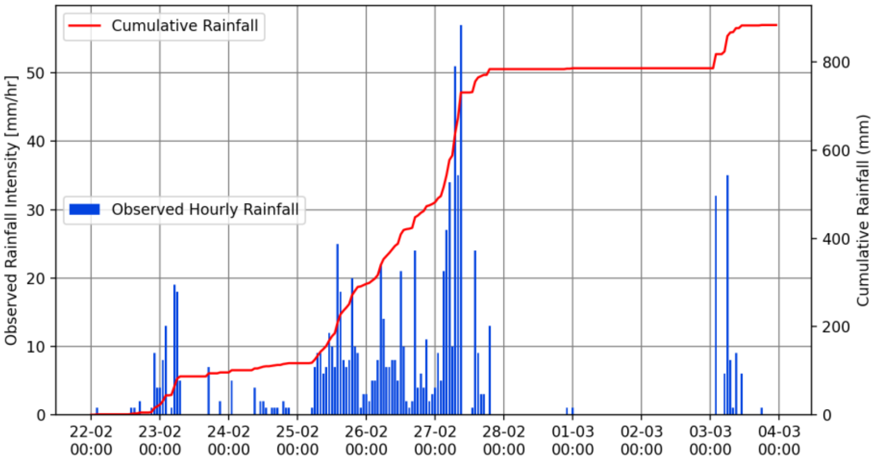


Figure A-1 Cumulative and sub-daily rainfall plot for Bribie Island Alert

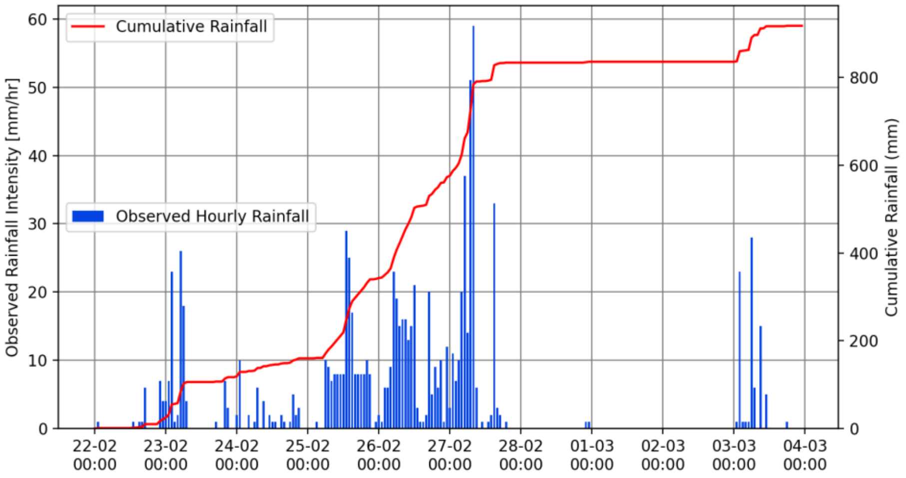


Figure A-2 Cumulative and sub-daily rainfall plot for Banksia Beach Alert

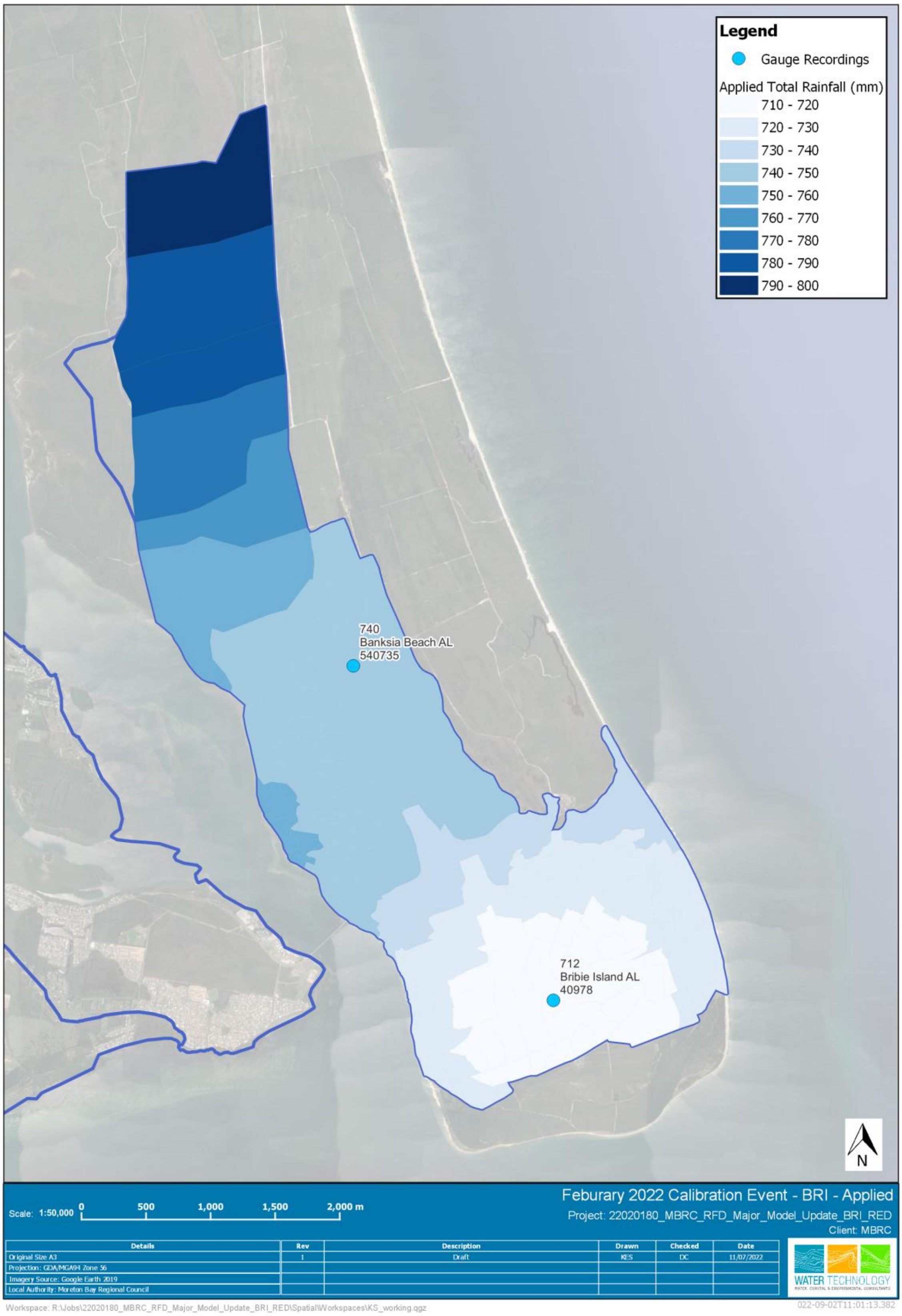


Figure A-3 Bribie Island WBNM subcatchment rainfall totals – February 2022

Figure A-4 show the recorded rainfall intensities and their estimated Annual Exceedance Probability (AEP) at the Bribie Island Alert (40978) and Banksia Beach Alert (540735) rainfall station respectively. AEPs were estimated by comparing the recorded rainfalls to design rainfall intensities from the Bureau of Meteorology's Intensity-Frequency-Duration (IFD) rainfall data for storm durations of up to 96-hours.

For Bribie Island Alert the data indicates the following:

- Rainfall intensities for storm durations of less than 2-hours had an AEP of between 10% and 5% AEP;
- The 3 and 6-hour storm durations had an AEP of between 2% and 1% AEP; and
- Storm durations of 12 hours and longer had an AEP between 2% and 1 in 500 AEP.

For Banksia Beach Alert the data indicates the following:

- Rainfall intensities for storm durations of less than 2-hours had an AEP of between 5% and 2% AEP;
- The 3 and 6-hour storm durations had an AEP between 2% and 1% AEP; and
- Storm durations of 12 hours and longer had an AEP between 2% and 1 in 500 AEP.

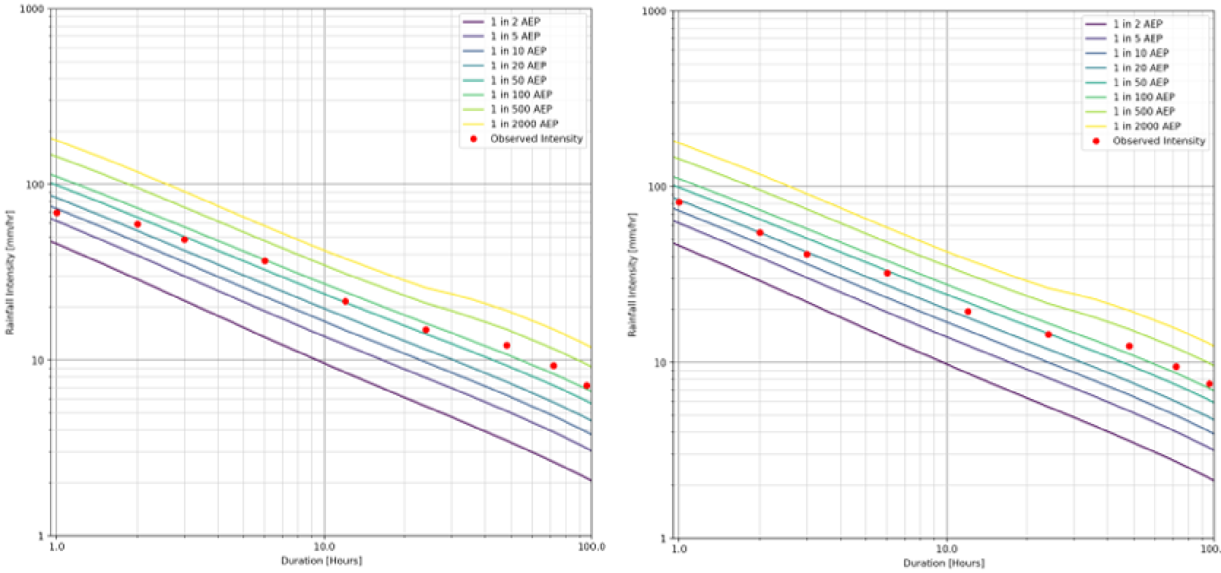
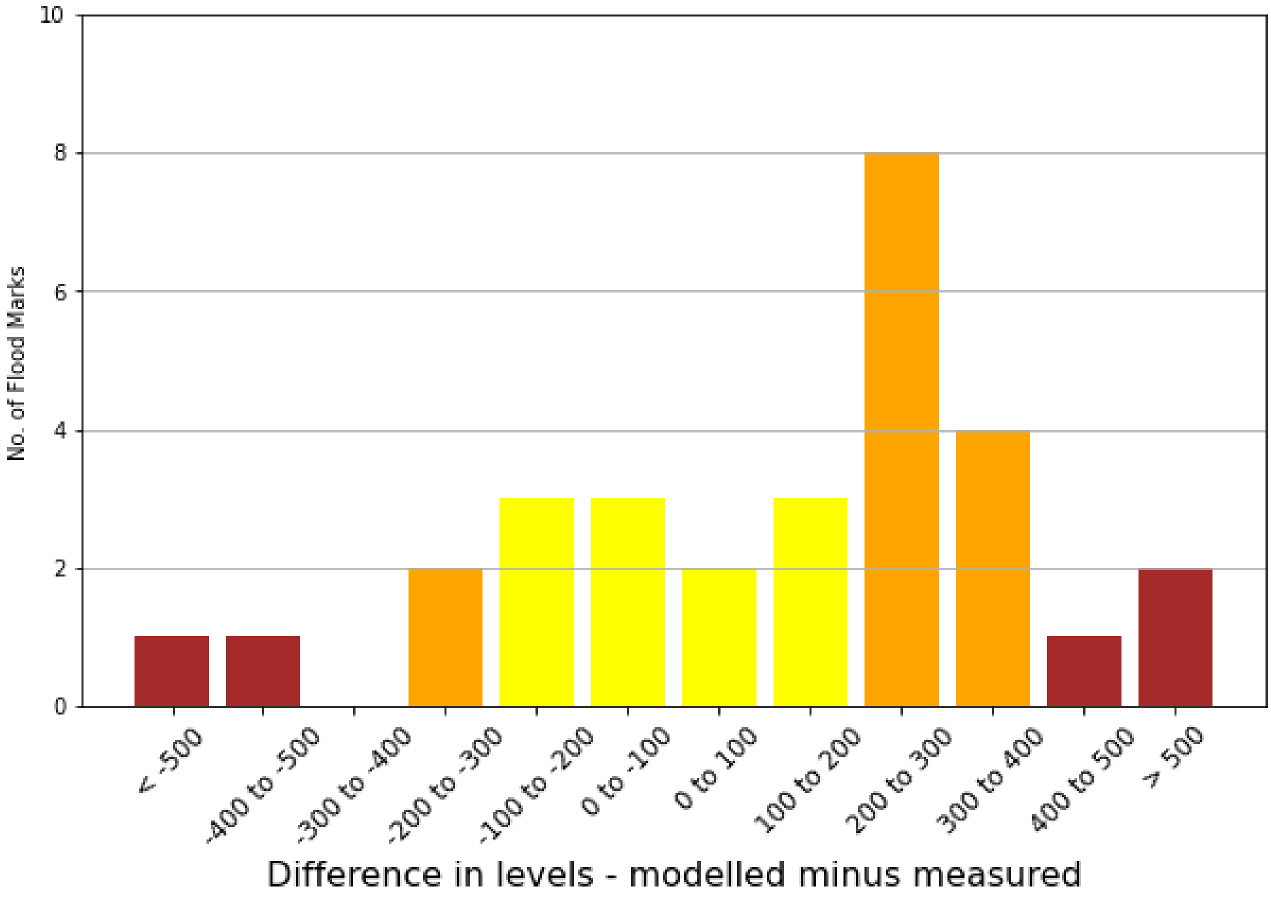


Figure A-4 Estimated AEP of February 2022 event for Bribie Island Alert (40978) (left) and Banksia Beach Alert (540735) (right)

A-2 Debris Histogram

A-2-1 February 2022



APPENDIX B
WBNM SUBCATCHMENT PROPERTIES

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
BON025_00000	8.86	1.6	1.1	1.4
BON008_00000	2.663	54	37.8	37.8
BON010_00000	2.945	32.5	22.8	22.8
FRE022_00000	7.819	39.8	27.8	33.1
FRE016_00512	2.719	0	0	10.6
FRE016_00234	2.212	0.2	0.1	2.7
FRE016_00063	1.002	4.7	3.3	4.1
FRE016_00000	0.157	0	0	0
FRE004_00801	7.334	0	0	0
FRE004_00488	11.506	5.2	3.7	3.7
FRE004_00000	15.095	0	0	0
FRE001_04347	12.174	0.2	0.2	0.2
FRE001_04206	1.705	0	0	0
FRE002_00124	14.602	2.3	1.6	1.6
FRE002_00000	1.193	0	0	0
FRE001_03912	20.979	0	0	0
FRE001_03472	15.039	0	0	0
FRE003_00000	20.555	0	0	0
FRE001_03202	2.375	0.3	0.3	0.3
FRE001_02976	12.746	2.4	2.3	2.3
FRE001_02842	14.971	0.9	0.9	0.9
FRE001_02684	15.045	0	0	0
FRE001_02442	7.666	0	0	0
FRE005_00531	8.983	2.3	1.6	1.6
FRE005_00252	9.296	2.8	2	2
FRE005_00000	4.457	0	0	0
FRE001_02249	1.709	1.1	0.8	0.8
FRE012_00373	1.975	0	0	0
FRE014_00305	14.682	8.9	6.4	7.4
FRE014_00000	2.043	12.9	9	9
FRE012_00000	7.56	22.4	15.7	15.7
FRE010_00616	52.916	0.4	0.4	0.4
FRE010_00000	7.735	1.2	0.8	0.8
FRE006_02999	45.59	9.4	7.5	7.5
FRE006_02350	28.379	8.7	6.7	6.7

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
FRE006_01891	20.352	6.9	5.3	5.3
FRE008_01206	13.798	0.4	0.3	0.3
FRE008_00837	15.639	0	0	0
FRE008_00430	14.341	0.8	0.8	0.8
FRE008_00000	7.521	4.3	4.1	4.1
FRE006_01416	16.349	4.6	4.5	4.5
FRE006_01263	6.826	6	4.2	4.4
FRE006_01141	0.702	23.5	16.4	16.4
FRE006_01008	5.218	37	25.9	25.9
FRE006_00587	7.593	7.9	5.5	5.5
FRE006_00144	3.432	20	14	14
FRE006_00000	0.686	17.3	12.1	12.1
FRE001_02182	0.633	20.3	14.2	14.2
FRE001_02107	2.197	4.3	3	3
FRE007_00373	6.985	2.7	1.9	1.9
FRE007_00125	3.608	54.8	38.3	38.3
FRE007_00000	0.522	1.1	0.8	0.8
FRE001_02092	0.073	0	0	0
FRE009_00030	4.886	48.4	33.9	33.9
FRE009_00000	0.191	13.8	9.6	14
FRE001_01915	1.259	11.8	8.3	9.1
FRE001_01047	25.633	20.7	14.5	17.7
FRE001_00854	8.641	37.8	26.5	28
FRE001_00623	4.968	50.3	35.2	42.3
FRE001_00429	10.846	45.3	31.7	31.7
FRE001_00080	6.413	14.4	10.1	10.1
FRE018_00758	6.828	42.5	29.8	33.6
FRE018_00549	8.053	47.3	33.1	33.1
FRE018_00294	12.481	45	31.5	31.5
FRE020_00000	3.614	44.2	31	31
FRE018_00175	5.007	46.6	32.6	32.6
FRE018_00000	1.698	43.3	30.3	30.3
FRE001_00000	7.098	22.1	15.5	15.5
DUX029_00000	8.319	39.1	27.4	29.2
BON015_00000	6.588	51.3	35.9	35.9

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
BON013_00238	10.718	66.2	46.4	46.4
BON013_00000	2.982	17.2	12	12
BON009_02749	14.708	1.8	1.3	1.3
BON009_02376	7.519	2	1.4	1.4
BON009_02197	3.342	3.5	2.6	2.6
BON011_00000	9.087	1.2	0.8	0.8
BON009_01946	19.077	35.2	34.9	35.1
BON009_01643	12.523	11.3	11.2	12.1
BON009_01378	15.84	10.1	9.6	10.7
BON009_00859	19.21	5.4	3.8	3.8
BON009_00673	23.282	22.1	15.5	15.5
BON009_00409	21.651	30.6	21.4	21.6
BON009_00050	12.96	44.6	31.3	31.5
BON009_00000	0.302	12.2	8.5	8.5
DUX011_00597	9.688	39.9	28	28
DUX013_00000	7.015	38.3	26.8	26.8
DUX011_00000	11.369	42.5	33.9	35.9
DUX017_00109	10.088	40.6	28.5	28.5
DUX017_00000	2.604	58.2	41.5	41.5
DUX009_00850	8.075	39.4	27.6	27.6
DUX009_00488	5.568	61.9	49.9	49.9
DUX009_00000	22.208	56.1	45.8	45.8
DUX009_00984	6.793	43.5	30.4	30.4
DUX007_00680	11.005	44.1	30.8	30.8
DUX007_00593	5.807	39.4	27.6	27.6
DUX007_00000	12.644	60.4	48.5	48.5
DUX003_00254	24.269	1.1	0.7	0.7
DUX019_00000	7.767	0	0	0
DUX003_00000	2.703	0	0	0
DUX001_09727	36.488	17.3	13.5	16.5
DUX001_09344	16.106	32.4	23.2	23.2
DUX001_09148	17.754	25.5	20.8	20.8
DUX001_07836	52.445	9	6.3	6.3
DUX016_02300	65.338	0.4	0.3	0.5
DUX016_01271	14.737	12.3	10.9	12.8

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
DUX016_00000	37.754	0.5	0.4	0.4
DUX001_07020	75.206	6.9	4.8	4.8
DUX001_05681	93.163	0.8	0.6	0.6
DUX014_03320	33.118	3	2.1	2.1
DUX014_01375	80.539	0.3	0.2	0.2
DUX014_00000	44.149	0	0	0
DUX001_04886	35.557	0	0	0
DUX001_04479	25.985	0	0	0
DUX001_04037	31.725	25.8	22.5	22.5
DUX005_00000	15.792	45.6	32.2	32.2
DUX001_03692	29.016	49.5	36.1	36.1
DUX001_03276	34.135	45.3	38.7	40.4
DUX018_00000	58.306	5.5	3.9	3.9
DUX001_02462	36.413	9.7	6.8	6.8
DUX023_00000	10.115	18.4	12.9	12.9
DUX001_01826	13.113	42.9	37.6	37.6
DUX001_01204	12.173	57.1	48.1	48.1
DUX032_00000	13.582	12.5	9	9
DUX002_00701	23.74	29.3	24.9	31.6
DUX002_00931	5.08	58.9	48.5	48.5
DUX002_00000	15.357	52.4	41.8	41.8
DUX030_00000	7.498	49	35.6	35.6
DUX001_00860	5.448	62.7	60.7	60.7
DUX022_00673	15.257	41.7	29.2	29.2
DUX022_00211	11.861	27.4	19.2	19.2
DUX022_00000	3.777	54.1	43.5	43.5
DUX001_00568	6.398	71	64.3	64.3
DUX010_00000	13.444	62.5	52.2	52.2
DUX006_00000	5.192	53.5	42.6	42.6
DUX024_00000	9.59	51.1	37.4	37.4
DUX026_00000	18.131	42.9	32.1	32.1
DUX004_02266	12.819	63.1	53.4	53.4
DUX034_00000	10.142	54.5	42.5	42.5
DUX004_01749	17.484	61.1	51.1	51.1
DUX004_01461	8.644	62.3	51.5	51.5

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
DUX008_01256	16.312	0.5	0.3	0.3
DUX008_00947	13.602	49.7	35.8	35.8
DUX008_00000	25.471	63.1	53.3	53.3
DUX004_00994	15.834	64	54.9	54.9
DUX004_00738	6.975	70.6	59.9	59.9
DUX012_00000	11.742	58.6	47.8	47.8
DUX004_00568	4.617	72.5	57.3	57.3
DUX004_00234	11.264	53.4	42	42
DUX004_00000	7.246	56.7	44.5	44.5
DUX001_00000	24.875	61.9	52.4	52.4
DUX033_00000	14.367	45.7	32	32
DUX021_00000	12.008	50.5	36.5	37.5
DUX015_00854	16.965	49.7	34.8	34.8
DUX015_00658	9.791	41.6	29.2	29.2
DUX015_00434	23.196	47.7	36.6	36.6
DUX015_00148	11.334	56	39.7	43.5
DUX015_00000	8.202	38.3	27	27.9
BON021_02138	30.191	5.5	3.8	4
BON021_01755	26.585	1.9	1.3	1.4
BON021_01366	21.515	18.8	13.1	13.1
BON021_01036	17.886	20.6	14.4	14.4
BON021_00612	13.365	20.2	14.1	17.1
BON021_00037	21.246	30.5	21.4	21.4
BON021_00000	4.193	36	25.2	25.2
WRI005_00000	7.867	29.2	20.4	20.4
WRI001_09295	316.937	0.5	0.3	0.3
WRI001_07271	375.693	0	0	0
WRI001_06339	200.629	0	0	0
WRI001_04044	336.751	0	0	0
WRI001_03180	219.941	0	0	0
WRI001_01749	290.284	0	0	0.1
WRI001_00960	49.11	0	0	0
WRI003_00554	66.238	18.1	13.5	17.2
WRI003_00000	8.229	0	0	0
WRI001_00227	55.369	1.4	1	1

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
WRI001_00160	0.63	2.9	2.5	2.5
WRI001_00000	3.811	2.9	2.1	2.1
WRI002_00042	54.085	10.4	7.3	7.7
WRI004_00000	7.129	17	11.9	11.9
WRI002_00000	0.601	0	0	0
FRE011_03915	21.519	0.3	0.2	0.2
FRE011_03612	29.099	0.9	0.6	0.6
FRE011_03161	15.919	1.3	0.9	0.9
FRE011_02732	21.094	1.2	0.8	0.8
FRE011_02354	17.744	1.1	0.8	0.8
FRE011_01833	12.914	0	0	0
FRE011_01513	25.831	9.2	6.4	6.4
FRE013_02268	22.717	0.9	0.6	0.6
FRE013_01251	26.518	0.8	0.6	0.6
FRE013_00431	27.907	0.1	0.1	0.1
FRE013_00000	14.964	0	0	0
FRE011_00785	31.023	1.4	1	1
FRE011_00000	10.379	7.8	6	6
BON004_00473	4.401	53.8	37.6	37.6
BON006_00000	7.864	42.9	30.1	30.1
BON004_00000	8.746	55.8	39.6	39.6
BON003_00141	19.906	2.3	1.6	1.6
BON003_00000	4.031	57.6	42.9	42.9
BON001_03469	6.713	0	0	0
BON001_03104	7.817	0	0	0
BON001_02640	15.265	1	0.7	0.7
BON001_02338	16.035	1.3	0.9	0.9
BON001_01940	18.512	58.1	45.4	45.4
BON001_01817	1.012	73.5	69.3	69.3
BON005_00000	18.856	56.7	42	42
BON001_01701	1.259	68.4	61.5	61.5
BON001_01176	20.217	55.6	44.8	44.8
BON001_00811	14.871	55.6	42.2	42.2
BON001_00664	1.279	65.4	58.5	58.5
BON002_00000	21.435	54.8	41.6	41.6

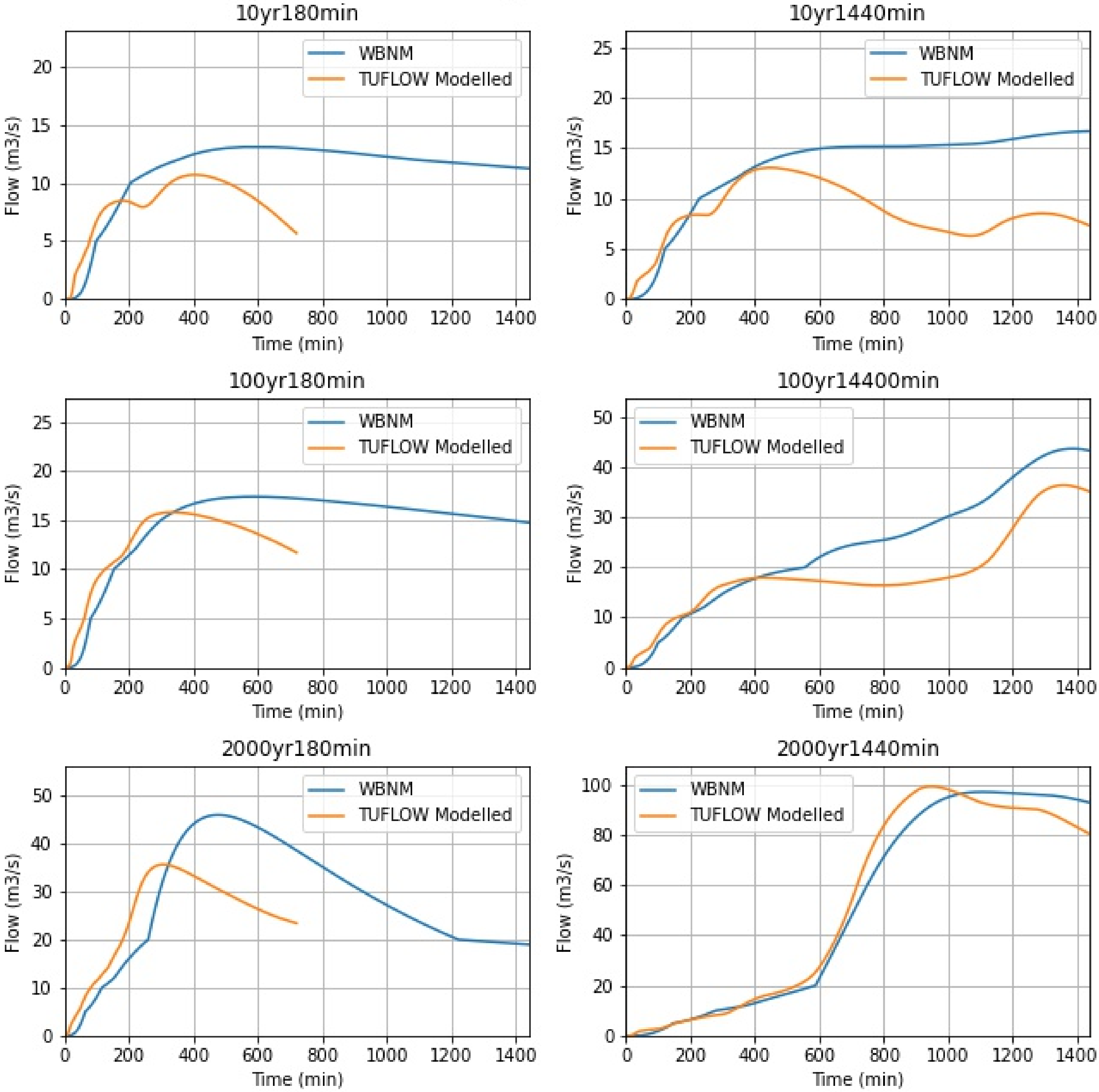
WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
BON001_00212	4.644	69	63.7	63.7
BON007_00000	43.259	54.1	37.9	37.9
BON001_00137	0.584	69.8	57.1	57.1
BON001_00000	3.842	30.5	25.1	25.1
DUX036_00000	4.741	33.3	24.2	24.2
DUX031_00000	16.195	38.9	27.2	27.2
DUX027_00000	3.025	46.4	32.5	32.5
DUX025_00000	3.82	47.6	33.3	33.3
DUX020_00511	4.056	49.6	34.7	34.7
DUX020_00195	6.931	34.5	24.2	24.2
DUX020_00085	3.925	46.4	32.5	32.5
DUX020_00000	3.97	31.8	22.3	22.3
BON017_00406	18.672	46.3	32.4	32.7
BON019_00000	6.27	50.1	35.1	35.1
BON017_00000	1.798	41	28.7	28.7
BON023_01795	14.238	2.2	1.5	1.5
BON023_01357	10.144	0.1	0.1	0.1
BON023_00920	12.427	0	0	0
BON023_00499	11.151	0	0	0
BON023_00172	5.489	31.6	22.1	22.1
BON023_00000	7.527	39.4	27.6	27.6
BON012_00000	5.394	36.9	25.8	25.8
FRE017_00000	5.799	7.1	5	5
FRE015_00000	1.716	26.6	18.6	20
DUMMY	0	100	100	100

APPENDIX C
HEH PLOTS AND SUMMARY TABLES

POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
WRI001_00227	✓	Bribie national park upstream with flat undulating terrain with undefined flowpaths	✗	Peak flows within 20% for all events. Unable to replicate loss of storage volume in Tuflow model.
FRE018_00175	✓	Trunk network has low capacity with ponding in Benny street increasing storage.	✗	4/6 events meet criteria in complex urban environment with trunk drainage.
FRE001_00623	✓	Significant catchment to the west which does not follow WBNM routing and is captured in small storages without outlets. Entire catchment drains towards trunk network which is capacity limited.	✗	Peak flows within 20% for all events. Unable to replicate loss of storage volume in Tuflow model.
DUX020_00000	✓	Significant storage upstream in Clayton Park which outlets to trunk drainage network.	✗	Peak flows within 20-40% overpredicted for all events. Unable to replicate loss of storage volume in Tuflow model.
DUX015_00000	✓	Significant storage upstream in Bibimulya wetland which outlets to trunk drainage network.	✗	Peak flows within 20-60% overpredicted for all events. Unable to replicate loss of storage volume in Tuflow model.
DUX001_04479	✓	Significant catchment to the east which does not follow WBNM routing and is captured in small storages without outlets.	✗	Poor match with both over and underestimation of peak flows for respective events. Unable to replicate loss of storage volume in Tuflow model.
DUX001_03276	✓	Dux lake immediately upstream attenuating flows.	✗	Peak flows within 30% for all events. Unable to replicate loss of storage volume in Tuflow model

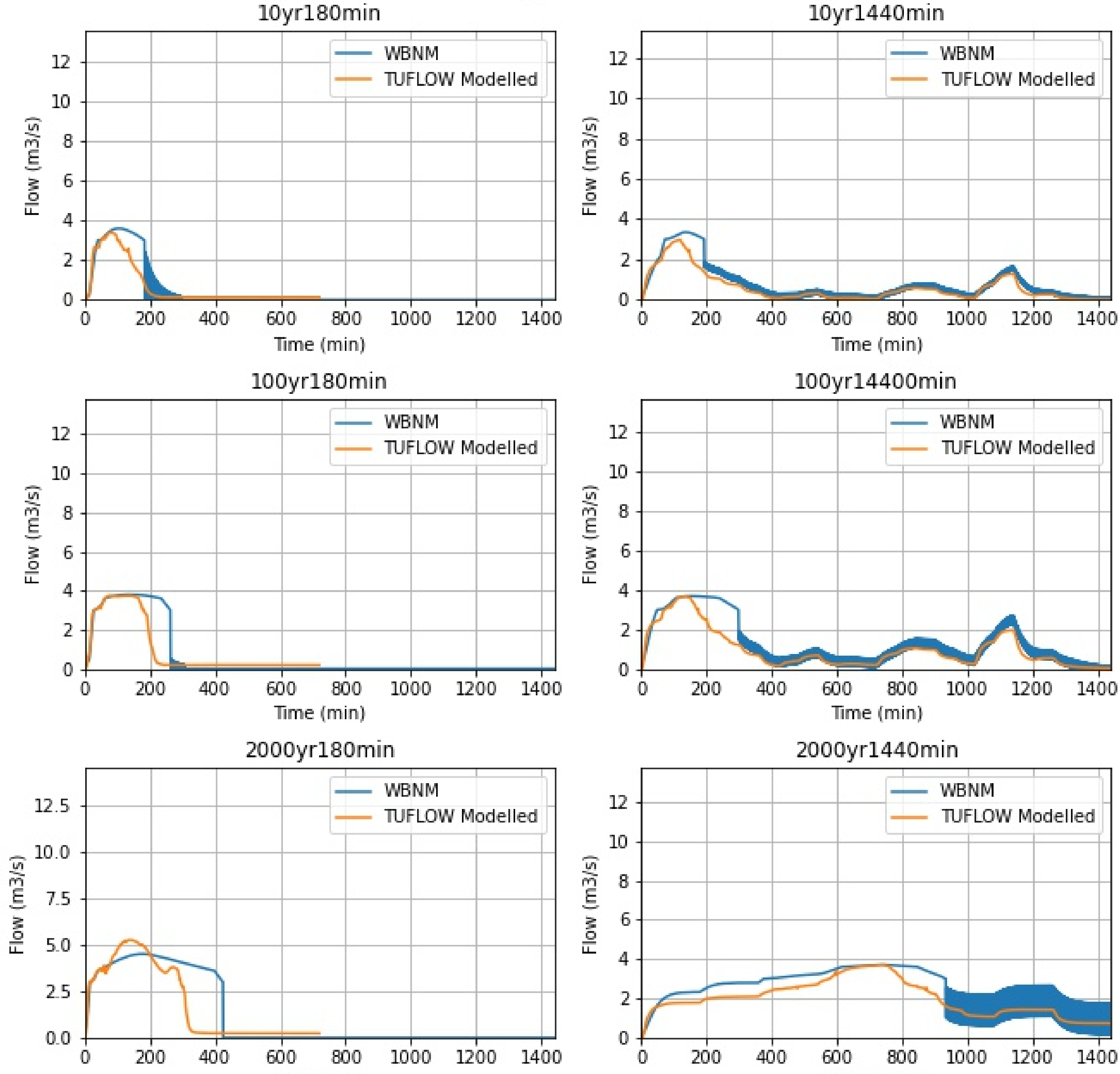
POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
DUX001_02462	✓	Flat terrain upstream of Sunderland Drive attenuating flows.	✗	Peak flows within 30% for all events. Unable to replicate loss of storage volume in Tuflow model
DUX001_00568	✓	Dux creek canals adding significant storage. Complex hydraulics with ocean tailwater influence.	✗	Good match considering complex hydraulics. Peak flows within 20%-40%.
BON021_00612	✓	Flat terrain upstream of Toorbul Street attenuating flows.	✗	Peak flows within 30% for all events. Unable to replicate loss of storage volume in Tuflow model. Good match of hydrograph shape for all events
BON009_00673	✓	Flat terrain upstream of Goodwin Drive attenuating flows.	✗	Peak flows within 40% for 10% and 1% AEP events. Poor match in 0.05% AEP event with catchment breakout flows unable to be replicated in WBNM model.
BON001_00137	✓	Bongaree canals adding significant storage. Complex hydraulics with ocean tailwater influence	✗	Peak flows within 30% for 10% and 1% AEP events. Good match of hydrograph shape for all events.

WRI001_00227



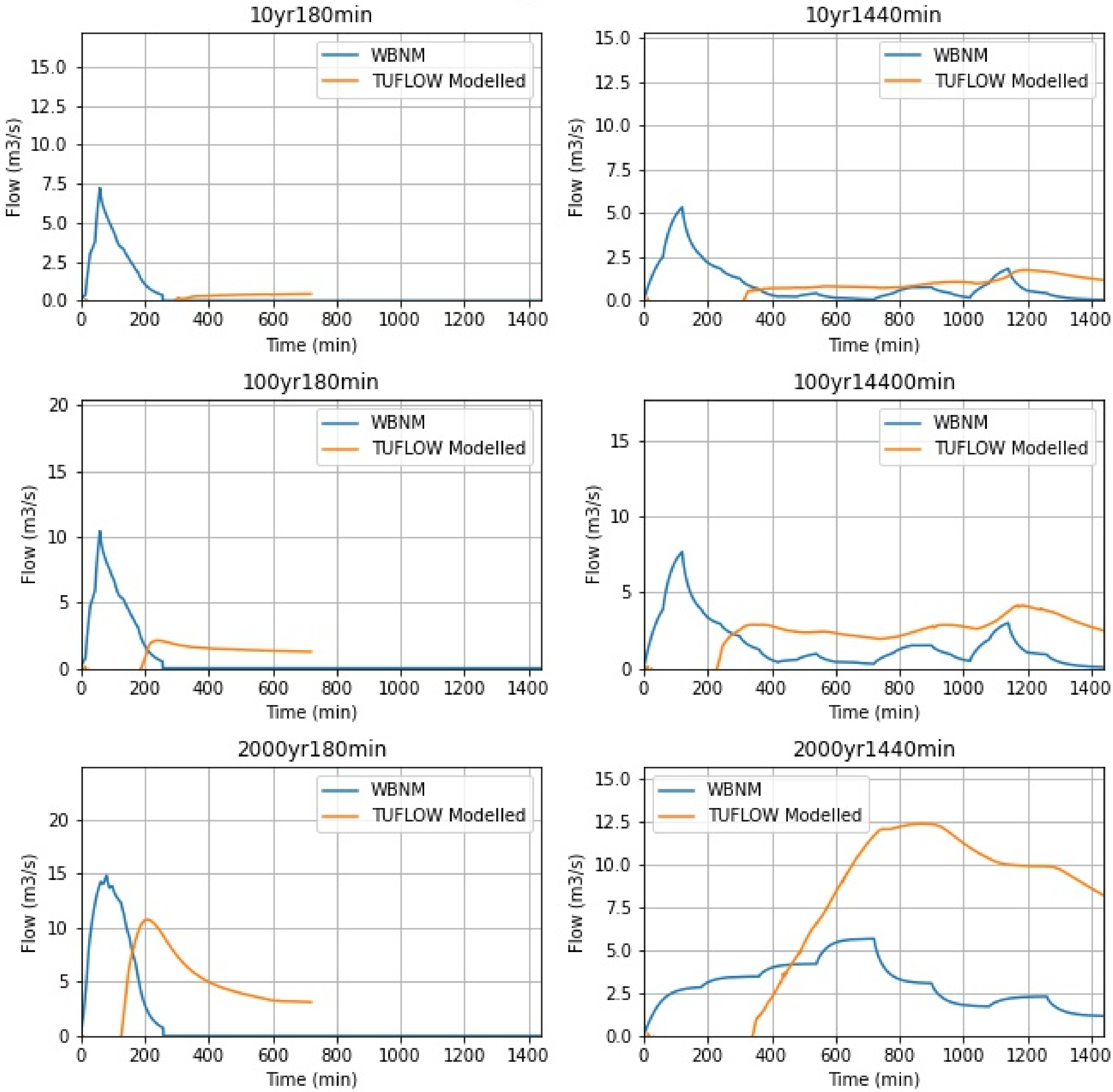
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	18.38%	184.0min	0.36
10yr1440min	21.8%	1019.0min	0.86
100yr180min	9.15%	244.0min	0.78
100yr14400min	16.71%	28.0min	0.9
2000yr180min	22.46%	170.0min	0.08
2000yr1440min	2.26%	157.0min	0.94

FRE018_00175



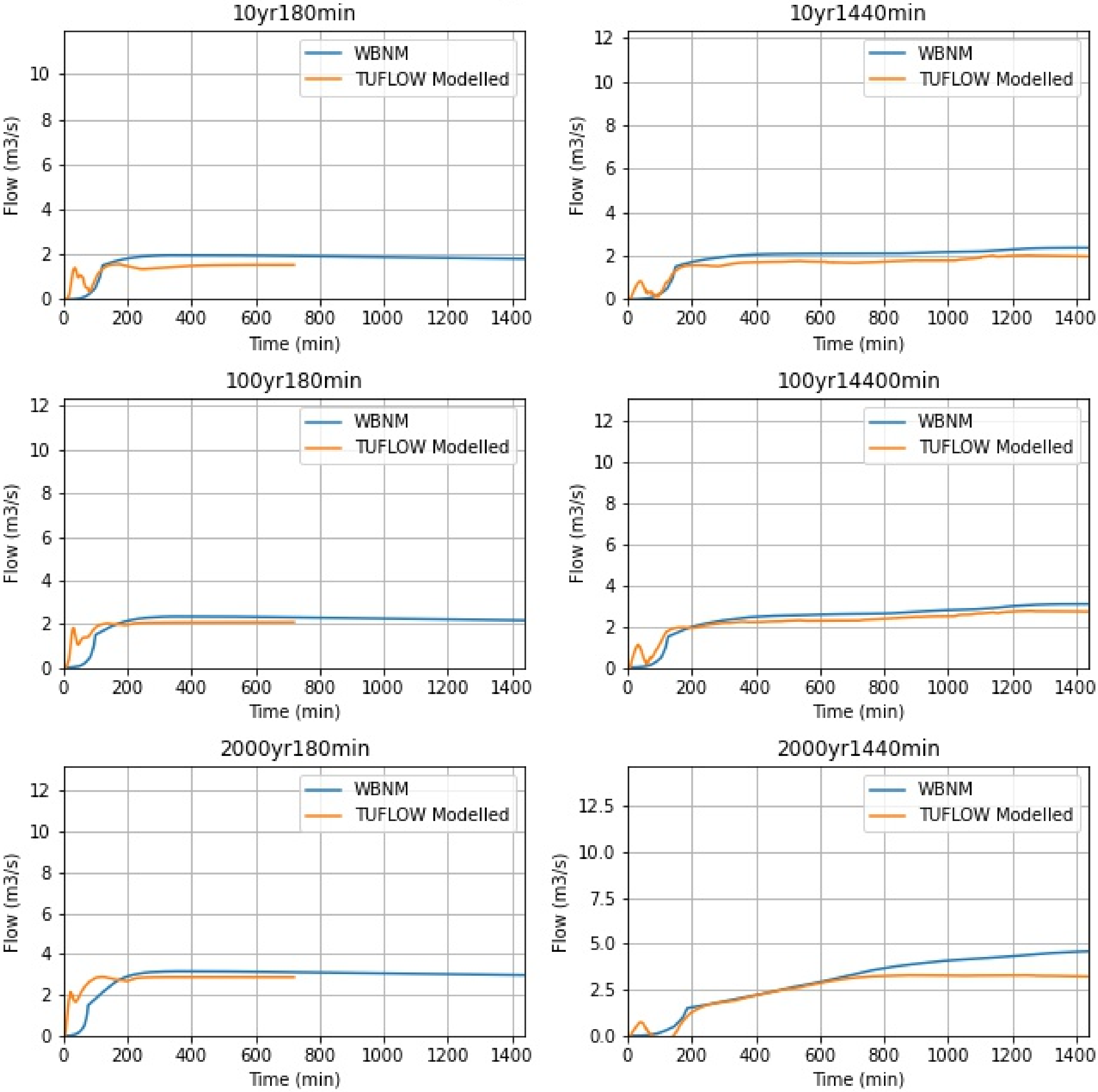
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	5.94%	21.0min	0.7
10yr1440min	11.23%	15.0min	0.72
100yr180min	1.34%	5.0min	0.52
100yr14400min	0.62%	18.0min	0.6
2000yr180min	16.85%	39.0min	0.45
2000yr1440min	0.4%	2.0min	0.44

FRE006_02999



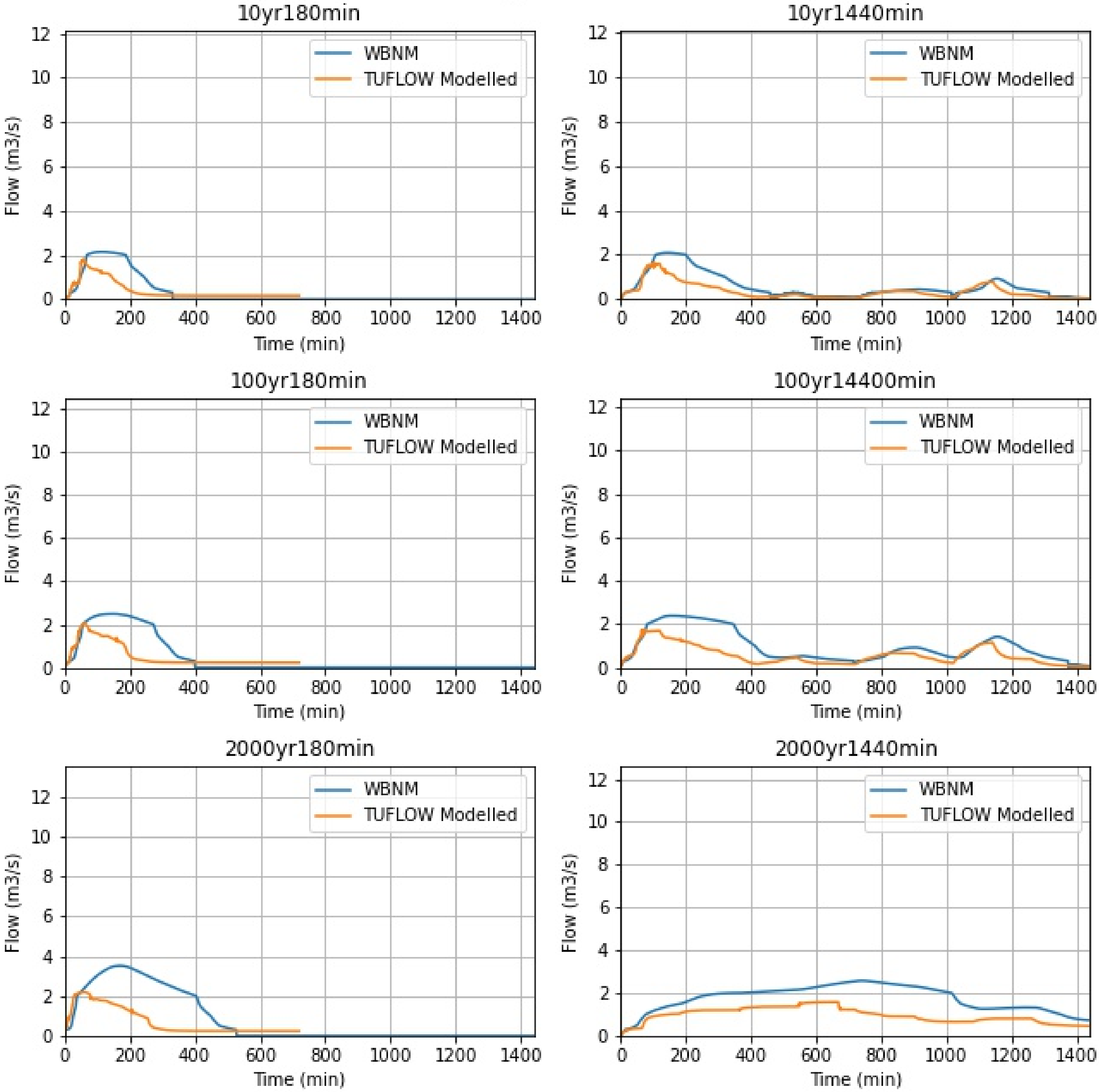
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	94.03%	658.0min	-1.6
10yr1440min	67.07%	1075.0min	-0.99
100yr180min	79.75%	179.0min	-2.7
100yr14400min	45.97%	1064.0min	-1.46
2000yr180min	27.4%	128.0min	-2.63
2000yr1440min	118.27%	152.0min	0.24

FRE001_00623



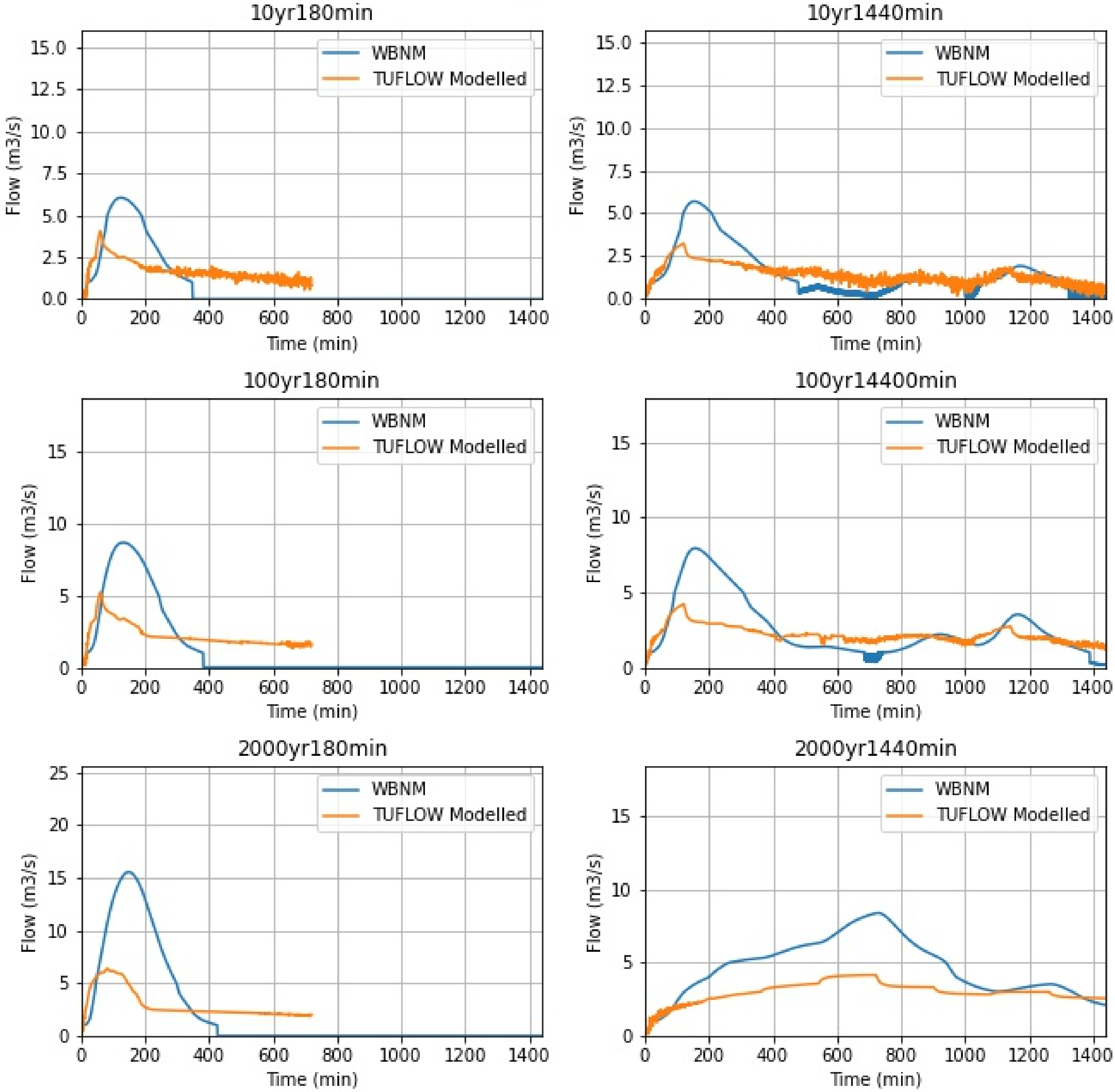
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	20.39%	223.0min	-0.36
10yr1440min	14.88%	121.0min	0.63
100yr180min	11.22%	332.0min	-0.39
100yr14400min	11.02%	132.0min	0.69
2000yr180min	8.62%	254.0min	-0.99
2000yr1440min	28.74%	660.0min	0.94

DUX020_00000



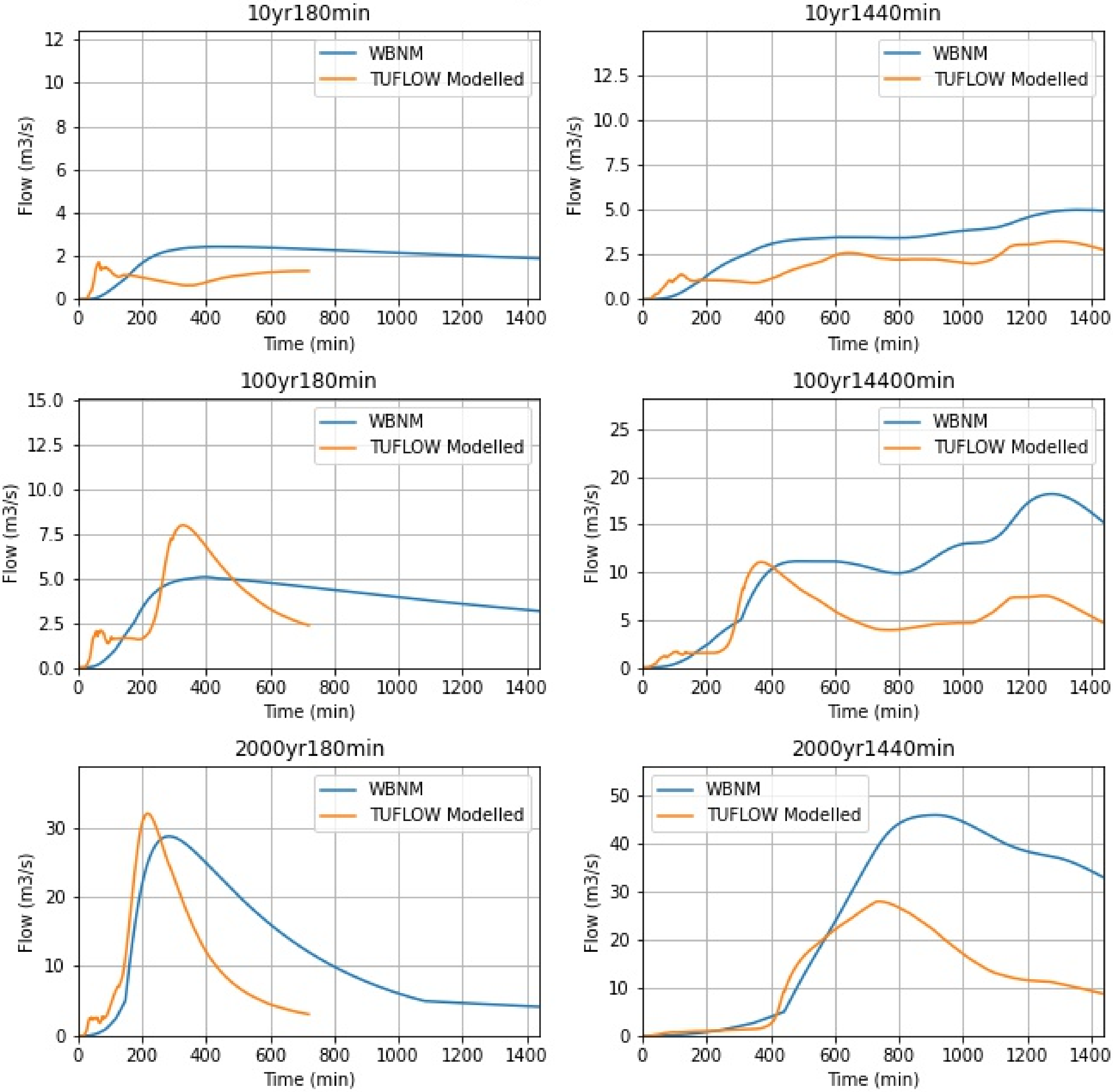
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	15.56%	53.0min	-0.39
10yr1440min	21.51%	42.0min	0.15
100yr180min	16.97%	83.0min	-0.51
100yr14400min	26.54%	85.0min	-0.07
2000yr180min	37.68%	107.0min	-0.31
2000yr1440min	38.76%	69.0min	0.16

DUX015_00000



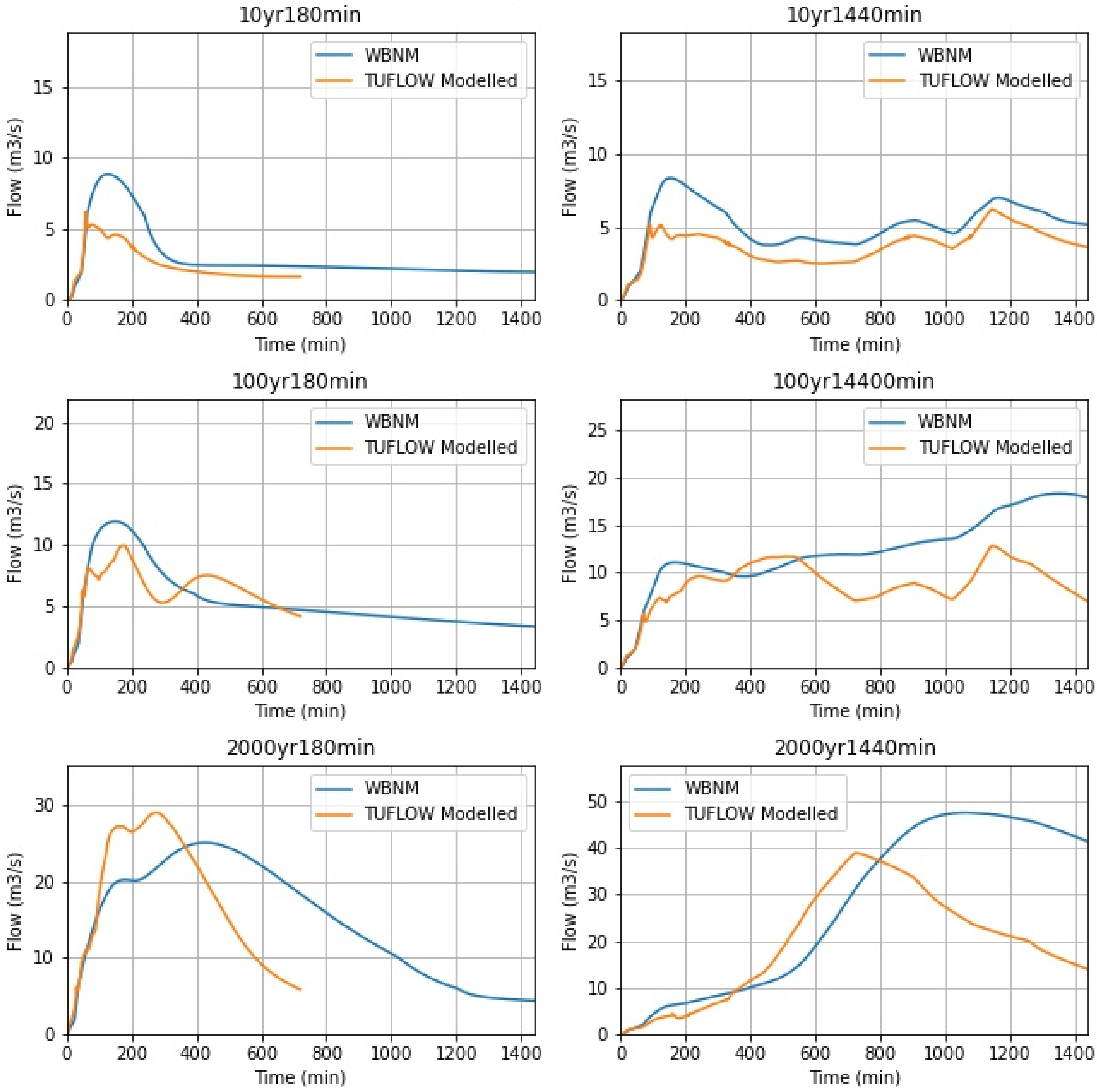
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	32.81%	63.0min	-6.48
10yr1440min	43.25%	34.0min	-2.63
100yr180min	39.82%	71.0min	-5.78
100yr14400min	46.87%	36.0min	-1.65
2000yr180min	58.83%	67.0min	-2.95
2000yr1440min	50.52%	8.0min	-0.07

DUX001_04479



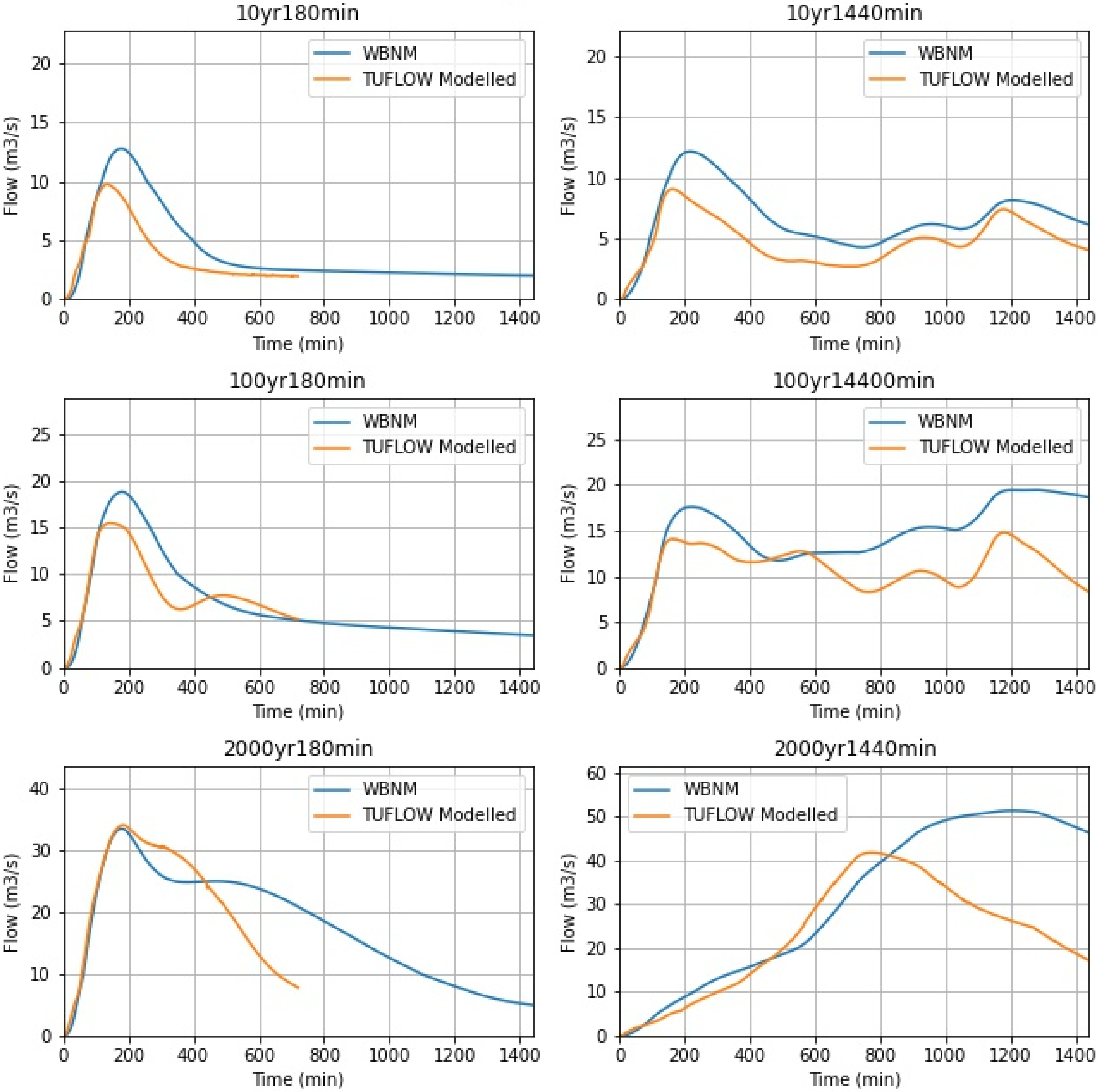
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	29.77%	368.0min	-1.02
10yr1440min	35.17%	66.0min	-0.67
100yr180min	57.29%	65.0min	0.63
100yr14400min	39.24%	905.0min	0.68
2000yr180min	11.52%	66.0min	0.26
2000yr1440min	39.15%	172.0min	0.93

DUX001_03276



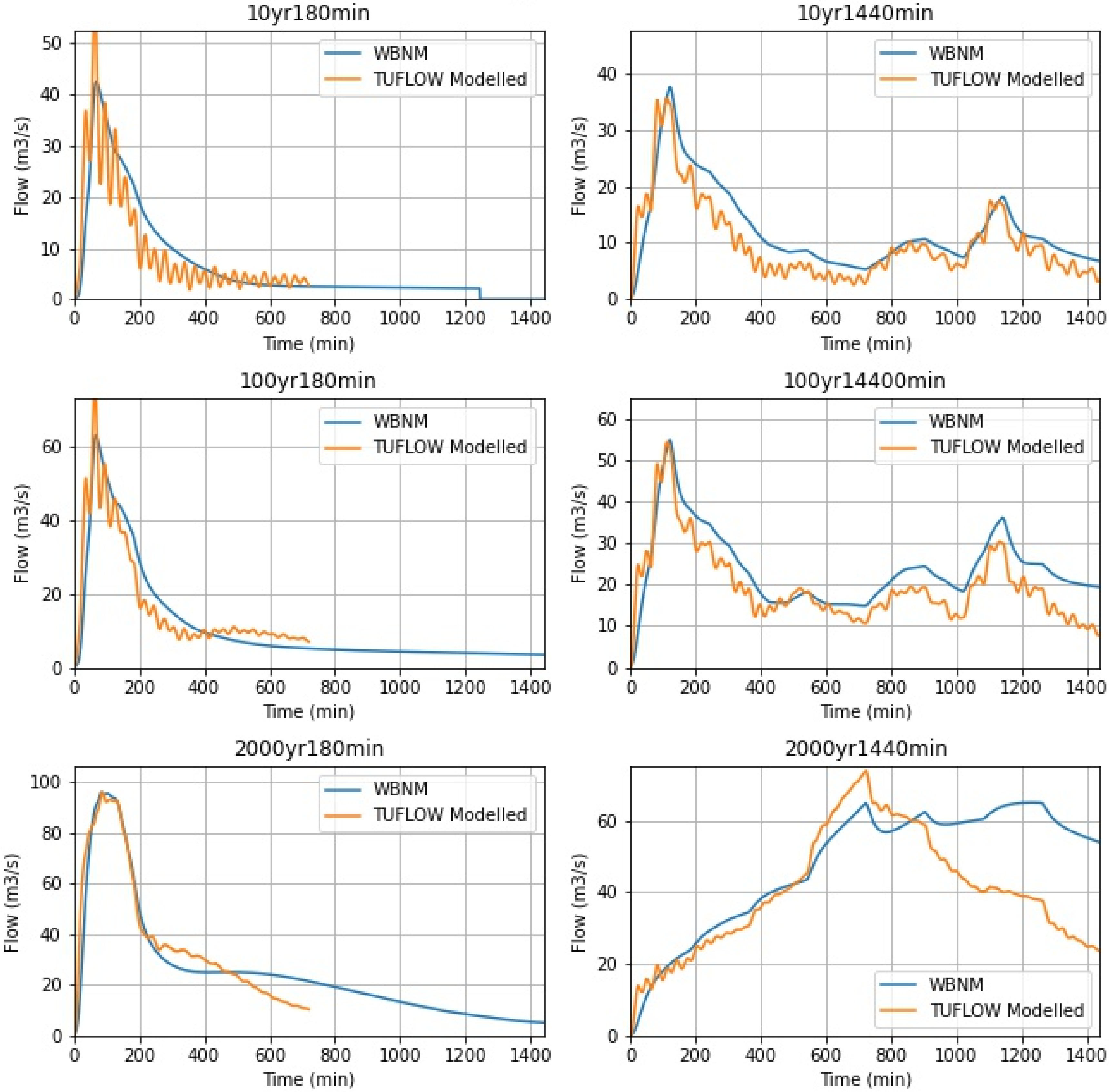
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	29.54%	66.0min	-0.11
10yr1440min	25.56%	988.0min	0.03
100yr180min	16.39%	27.0min	-0.09
100yr14400min	29.96%	205.0min	0.73
2000yr180min	15.68%	148.0min	0.26
2000yr1440min	18.2%	333.0min	0.73

DUX001_02462



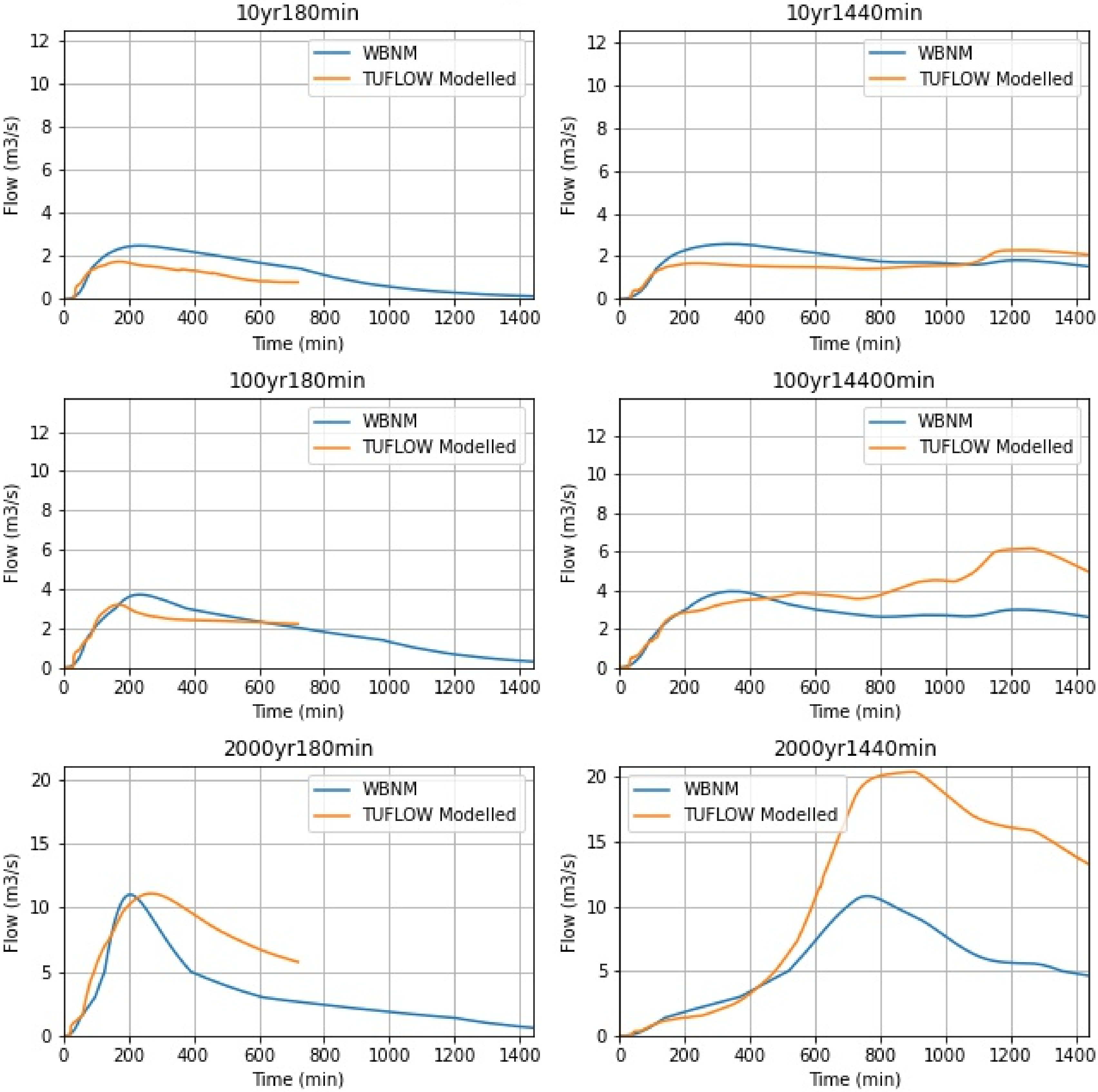
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	23.59%	42.0min	0.33
10yr1440min	25.32%	54.0min	0.28
100yr180min	17.83%	34.0min	0.54
100yr14400min	24.06%	91.0min	0.71
2000yr180min	1.74%	4.0min	0.8
2000yr1440min	18.66%	433.0min	0.9

DUX001_00568



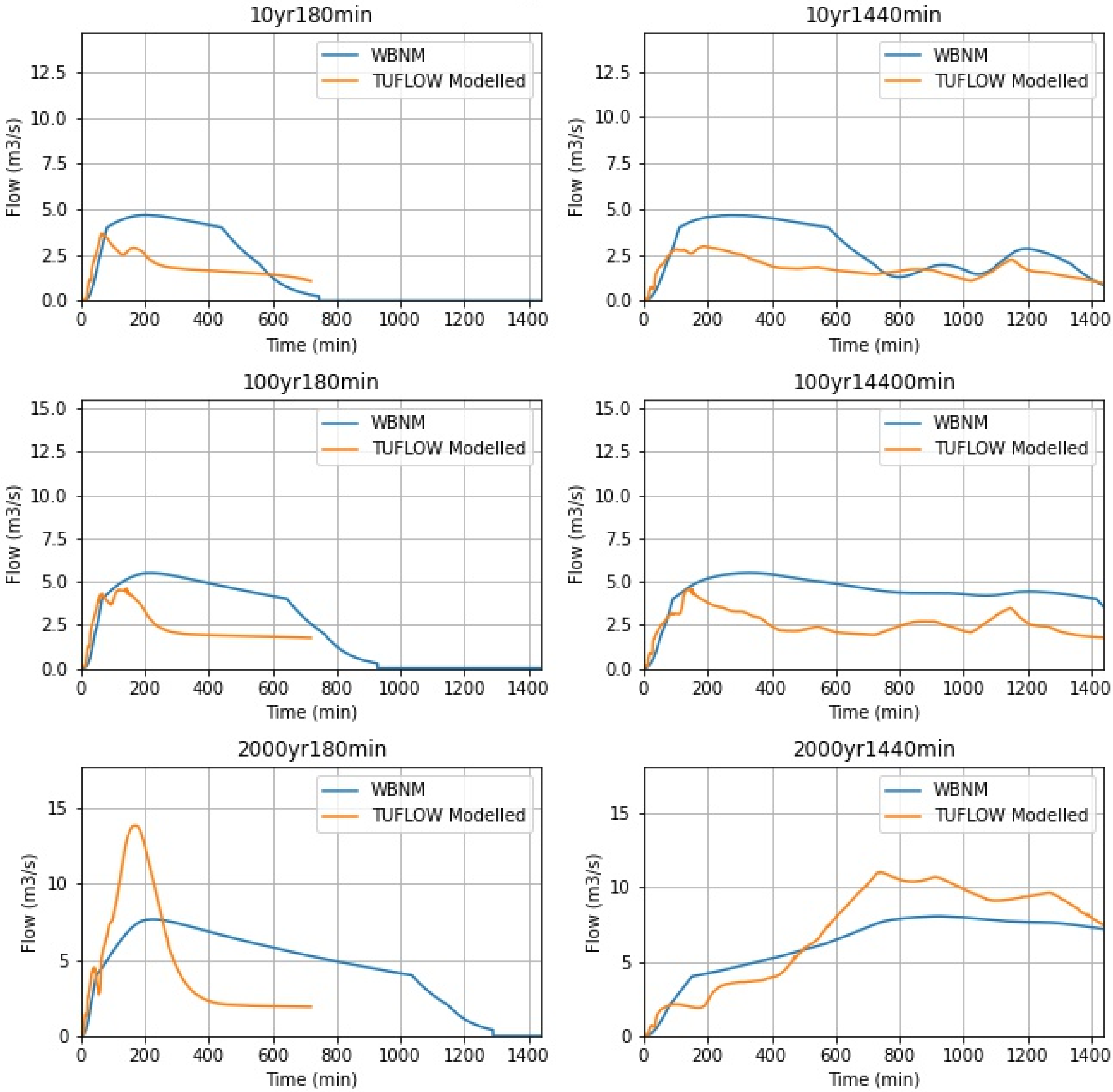
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	39.05%	4.0min	0.73
10yr1440min	5.56%	9.0min	0.72
100yr180min	21.26%	3.0min	0.83
100yr14400min	0.73%	7.0min	0.79
2000yr180min	0.04%	2.0min	0.93
2000yr1440min	13.66%	504.0min	0.93

BON021_00612



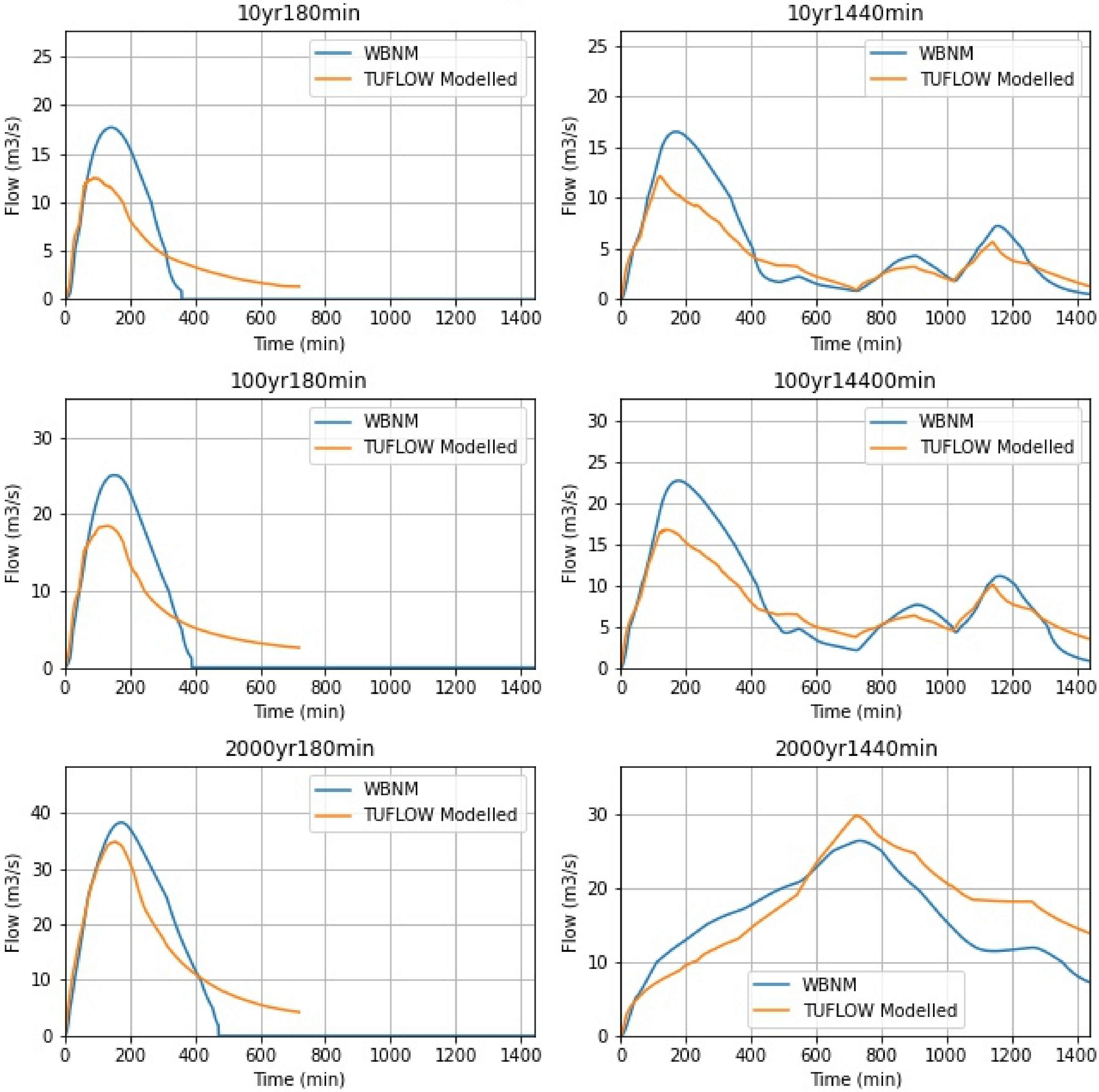
	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	29.72%	59.0min	0.05
10yr1440min	11.32%	923.0min	0.11
100yr180min	13.99%	62.0min	0.55
100yr14400min	56.3%	915.0min	0.86
2000yr180min	0.83%	64.0min	0.4
2000yr1440min	88.94%	142.0min	0.88

BON009_00673



	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	21.13%	134.0min	-0.28
10yr1440min	36.39%	86.0min	-0.19
100yr180min	15.99%	73.0min	-0.15
100yr14400min	16.83%	175.0min	-0.18
2000yr180min	80.58%	49.0min	0.12
2000yr1440min	36.82%	187.0min	0.67

BON001_00137



	Peak diff (%)	Peak timing diff (min)	NSE
10yr180min	29.44%	54.0min	-0.06
10yr1440min	26.4%	47.0min	0.11
100yr180min	26.32%	22.0min	0.15
100yr14400min	26.15%	41.0min	0.27
2000yr180min	9.0%	18.0min	0.68
2000yr1440min	13.04%	11.0min	0.76

APPENDIX D
POI ARF CLASSIFICATION

POI ID	Area km^2	ARF class
DUX020_00000	0.26	A
FRE018_00175	0.36	A
FRE006_02999	0.46	A
DUX015_00000	0.69	A
BON021_00612	1.10	A
BON009_00673	1.38	A
BON001_00137	2.37	B
FRE001_00623	5.44	C
DUX001_04479	6.63	C
DUX001_03276	7.74	C
DUX001_02462	8.68	C
DUX001_00568	11.25	C
WRI001_00227	19.19	C

APPENDIX E
HEH METHODOLOGY MEMO

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Technical Note

Project	A11567 – RFD 2021 Major Update		
From:	Blair Filer, Richard Sharpe, Anne Kolega		
Date:	05/07/2023	To:	Hester van Zijl, MBRC Alana Mosely, MBRC Bonnie Beare, MBRC
Doc Ref:	T.A11567.018		
Subject:	Final HEH Modelling Methodology		

Overview

This Technical Note has been prepared to describe BMT's proposed method for developing the hydraulically equivalent hydrology (HEH) models for the RFD 2022 Major Update project. BMT note that two prior HEH methodologies were developed by Moreton Bay Region Council (Council)[1], and ARUP/HARC[2], and were provided as part of the project brief. BMT has considered these prior methodologies and developed a revised method with the aim to build a hydrologic model that has hydraulic equivalence at nominated points whilst limiting the divergence to the hydraulic model outside of these nominated points. The method uses the in-built stream routing before applying any additional (artificial) storage. The method also used an alternative approach to developing the artificial storages by using the continuity equation. In addition, assessment criteria have been formalised to inform the suitability of the selected stream routing or the derived artificial storage.

The nominated points (referred to as HEH points in this Technical Note) were selected to meet the requirements of the 2022 RFD update project. This approach limits revisions of the HEH modelling when including additional points for future projects. However, it is noted that some locations are influenced by backwater (tidal zones, large dams), or have unaccounted additional storage (local road crossings, farm dams, off-river waterbodies), where hydraulic equivalence will only occur at the nominated points.

Aim

The aim of the HEH model methodology is to ensure that the hydrologic model (WBNM) hydrographs provide a reasonable 'match' to the hydraulic model (TUFLOW) hydrographs at nominated HEH points across the catchments. The match is considered in respect to peak discharge, the timing of the peak discharge (maximum) along with other minor 'peaks', and the general shape of the rising and falling limbs of the hydrograph.

The purpose of the HEH (WBNM) model is to select 'critical' temporal patterns and durations in the hydrology model when using the latest Australian Rainfall and Runoff (ARR2019) guideline. This selection process is expected to limit the simulation of all temporal patterns and durations for each annual exceedance probability (AEP) design events in the hydraulic model to just the 'AEP neutral' simulations. This process is expected to reduce the number of hydraulic simulations required and

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[1] Moreton Bay Regional Council (2022), "*Calibration and HEH Modelling for BCC Catchment (WBNM and TUFLOW)*"
[2] ARUP (2021), "*Regional Flood Database ARR 2019 Pilot Study: Part 1 Methodology Report & Part 2 Pilot Study Report*"

provide a more efficient procedure in temporal pattern and duration selection, and to reduce the complexity of the application of the ARR2019 guideline.

BMT's method is designed to initially use WBNM's stream lag factor as a primary source of 'matching' the two different hydrographs. If a satisfactory match cannot be achieved through adjustment of the stream lag factor, then a second step of adding 'artificial' storage to improve the match between the two hydrographs is undertaken.

Comparison points, where the match is assessed, are selected within each catchment. Throughout this Technical Note, these locations are referred to as 'HEH points' which have been defined as points of interest (POI) in the RFD 2021 Major Update project. The group of contributing sub-catchments to each HEH point is referred to as the 'HEH Area'. An example of sub-catchments, the HEH points and HEH areas are shown in Figure 1.1.

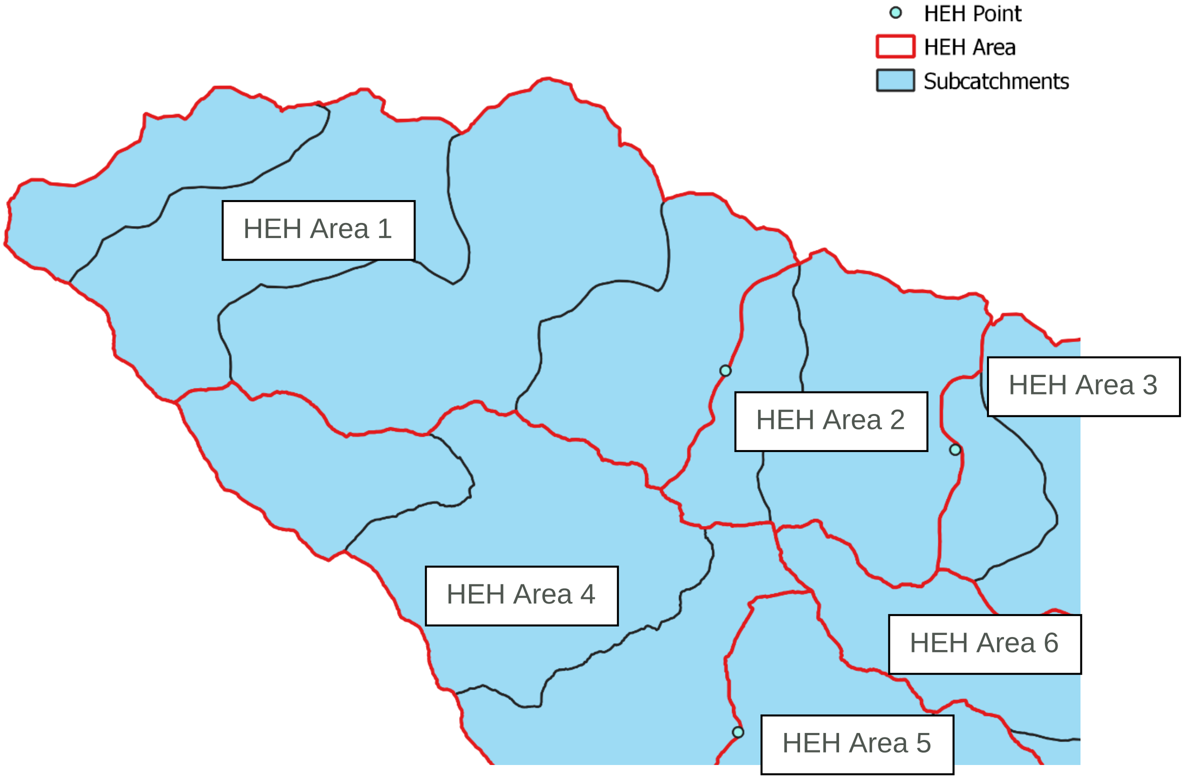

Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

The remainder of this Technical Note includes the following sections:

- Definitions
- Specifications – number of model simulations, and identification where artificial storages may be required.
- Proposed matching criteria for peak discharge, the timing of the peak discharge (maximum) and the general shape of the hydrographs at each HEH point.
- A step by step run through of the process to 'match' the HEH (WBNM) model and the TUFLOW model at an HEH point.

Definitions

- Annual Exceedance Probability (AEP) – this terminology is used when referring to design rainfall-runoff events using Australian Rainfall and Runoff 2019 (ARR2019) methodology.
- Average Reoccurrence Interval (ARI) – this terminology is used when referring to design rainfall-runoff events using Australian Rainfall and Runoff 1987 (ARR1987) methodology.
- Lag Parameter (C_c) – the parameter within WBNM used to influence the storage within each sub-catchment.
- Stream Lag Factor (C_s) – the factor within WBNM used to influence the storage within channels that 'links' the upstream sub-catchment to the downstream sub-catchment (channel routing). The storage to flow relationship is non-linear and the calculation is dependent on the associated lag parameter of the downstream sub-catchment.
- Artificial storage – storage used in addition to that represented by the stream lag factor within the HEH (WBNM) model. This is referred to as 'artificial' as it is in addition to the channel routing storage applied to the model. This storage is implemented using the water level–storage–outflow (HSQ) relationships at the downstream end of the channel link. HSQ relationships are level-pool storages (or dam storages) which have a linear storage-flow relationship.

Specifications

Model simulations

The HEH methodology will use Council's ARR1987 design rainfall events to inform the development of the HEH model. Using ARR1987 provides a greater spectrum of peak discharges and catchment responses than using a limited number of calibration events. BMT therefore proposes that a range of ARI and durations are used.

At a minimum, one infrequent design event and one rare ARI event design event should be used, however BMT recommends selection of at least two events in each bucket[3]. Given that the HEH methodology is required to work up to the 0.05% AEP event (equivalent to the 2000-year ARI event), a rare ARI event (2000-year ARI event) should also be used. For ease of implementation, scaling of Councils existing 1000-year ARI event to the equivalent 2000-year event if the 2000-year ARI is not available.

One short duration, one medium duration, and long duration temporal pattern should ideally be selected for each ARI simulated (range of critical durations). However, the selection of these temporal patterns will be dependent on the catchment characteristics, such as size and critical duration within each catchment.

For the best outcome, simulation of a larger number of events (ARIs and durations) will give more assurance that the HEH modelling achieves the desired results across a range of floods.

Identification of artificial storages at HEH point

The requirement to include artificial storages should be reviewed for each HEH point. At a high-level, the need for artificial storage would be expected in areas with known storages (weirs, sand mines, regional detention basins, lakes), large floodplain areas, tidally influenced areas, and transitions from fast flowing narrow areas to slower flowing wide areas (or vice versa).

The following factors may be an indication that the addition of artificial storage is required:

- The 'HEH calibrated' stream lag factor of an HEH area is outside the WBNM recommended guidelines of 0.5 for constructed earth channels and 1.0 for natural channels[4]. BMT notes that higher or lower stream lag factor can also be used if the hydrographs match well across simulated ARI and temporal patterns.
- The initial rising limb in the TUFLOW occurs much later than the WBNM (see example in Figure 1.2)
- Large differences occur in peak discharge and timing between different ARIs when using the same duration.
- Large differences occur in peak discharge and timing between different durations applied for the same ARI.

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[3] ARR1987 splits temporal patterns into two ARI buckets (above and below the 30-year ARI)

[4] BMT notes that these values are understood to be based on a lag parameter of 1.7, the average value found in the WBNM guidelines. Values may need to be scaled up or down with the selected lag parameter best suited to the catchment (established during the calibration process).

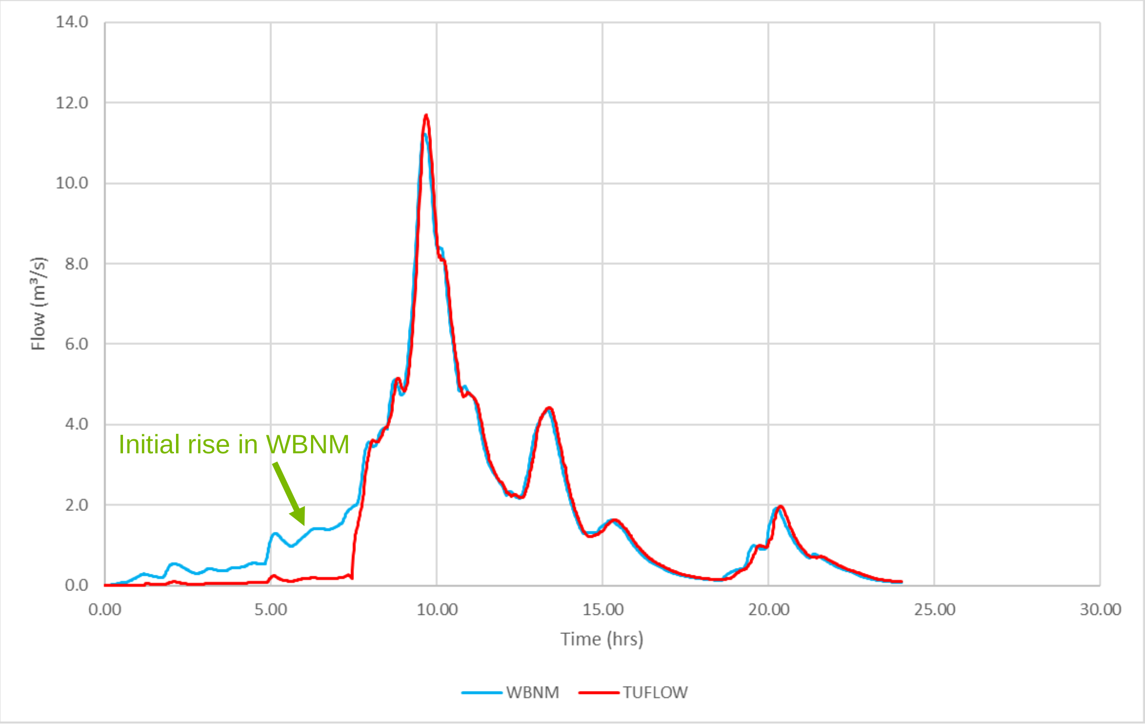

Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

Criteria for ‘matching’ the hydrographs at each HEH point

Hydrographs from WBNM and TUFLOW models at selected HEH points are required to be compared. The purpose is to achieve a ‘match’ of the WBNM hydrograph to the TUFLOW hydrograph regarding the following 3 criteria:

- The timing of the peak discharge between WBNM and TUFLOW should generally be within 15 minutes, in particular for HEH points in the upper catchment. This criterion of 15 minutes may need to relaxed in the downstream parts of large catchments where greater emphasis can be placed on matching the overall hydrograph timing and shape.
- The difference of the WBNM peak discharge should be within 10% (ideally within 5%) of the TUFLOW peak discharge.
- The shape of the hydrograph should also be reviewed by eye, giving greater emphasis to matching the rising limb[5]. Whilst parameterisation of the shape is at the modeller’s discretion, it is recommended to either calculate the volumetric difference, with the difference being no less than 10%, or using the Nash-Sutcliffe calculation, achieving a criterion of the Nash-Sutcliffe calculation greater than 0.95 (using TUFLOW as the ‘observed’ data).

Timing of the peak discharge is expected to be the most important of the above criteria as this can significantly influence the peak flow magnitudes at confluences where flow converges.

Whilst ‘matching’ across all ARI and durations is desirable, BMT notes that each HEH point is only required to ‘match’ well for durations around the expected critical duration based on ARR2019 (for example, the HEH model should demonstrate a satisfactory match between WBNM and TUFLOW for durations between the 30 minute and 2-hour storms if the critical duration is 1 hour).

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[5] Falling limbs can be dependent on baseflow which cannot be calculated in WBNM.

Detailed Steps

A flow chart of the process for implementing the HEH model methodology is provided in Figure 1.3 and further described in the following sections.

Flowchart

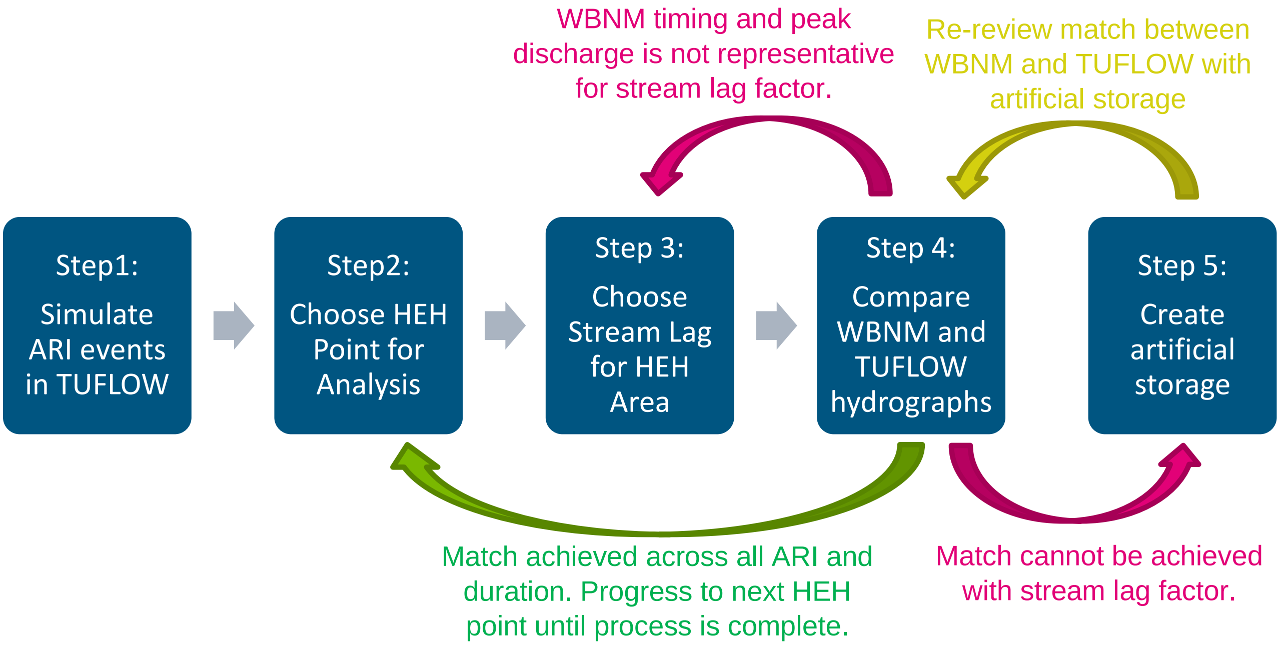

Figure 1.3 Flow chart for the HEH model methodology

Step 1: Simulate ARI events in TUFLOW

Select a range of ARI events and durations (using ARR87), refer to ‘Model simulations’ in the Specifications section for guidance on this selection. Simulate the selected ARI and durations in the TUFLOW model with plot outputs (‘PO’) included at each HEH point. Inflows to the TUFLOW are required to be all ‘local’ flows derived from the WBNM model using the selected lag parameter from calibration.

Step 2: Choose a HEH point for Analysis

Choose a HEH point to review the hydrographs against the ‘matching’ criteria. The initially selected HEH point should be the most upstream point that is not yet ‘matched’. Only once an upstream HEH point achieves a ‘match’ the downstream HEH point can be reviewed. Similarly at confluences, only once the HEH points on both tributaries’ ‘match’, the HEH point at the confluence or downstream of the confluence should be reviewed.

Step 3: Choose a stream lag factor for the WBNM model

Choose a stream lag factor for the entire HEH area. The stream lag will be applied to all sub-catchments within the HEH area. If different sections of the HEH area require different stream lag factors, it is recommended that an additional HEH point is included.

The initial stream lag should be based on the WBNM recommended guidelines of 0.5 for constructed earth channels and 1.0 for natural channels. The next iteration of the stream lag factor will be based on the review of hydrographs in Step 4. A decrease in the stream lag factor will shorten the timing and increase the peak discharge ('peakier' event), whilst an increase does the opposite.

Once a stream lag factor is chosen, the WBNM model should be simulated for all nominated ARIs and durations.

Step 4: Compare against TUFLOW hydrograph

The hydrographs at the selected HEH point should be analysed against the criteria (refer to Criteria Section). Where an HEH point does not meet the criteria across the nominated ARI events and durations, either the modeller needs to revisit the stream lag factor (Step 3) or, if stream lag adjustments are unlikely to achieve a desired match, consider adding an artificial storage (Step 5).

Should the modeller consider artificial storage, it is recommended that the stream lag factor is revisited first, to generate 'ideal' hydrographs across the ARI and durations. The 'ideal' hydrograph for implementing an artificial storage is when the peak WBNM discharge is higher and the WBNM timing is earlier than that in the TUFLOW model. An example of an 'ideal' WBNM hydrograph prior to adjustment using artificial storage (via application of a HSQ rating curve) is shown in Figure 1.4.

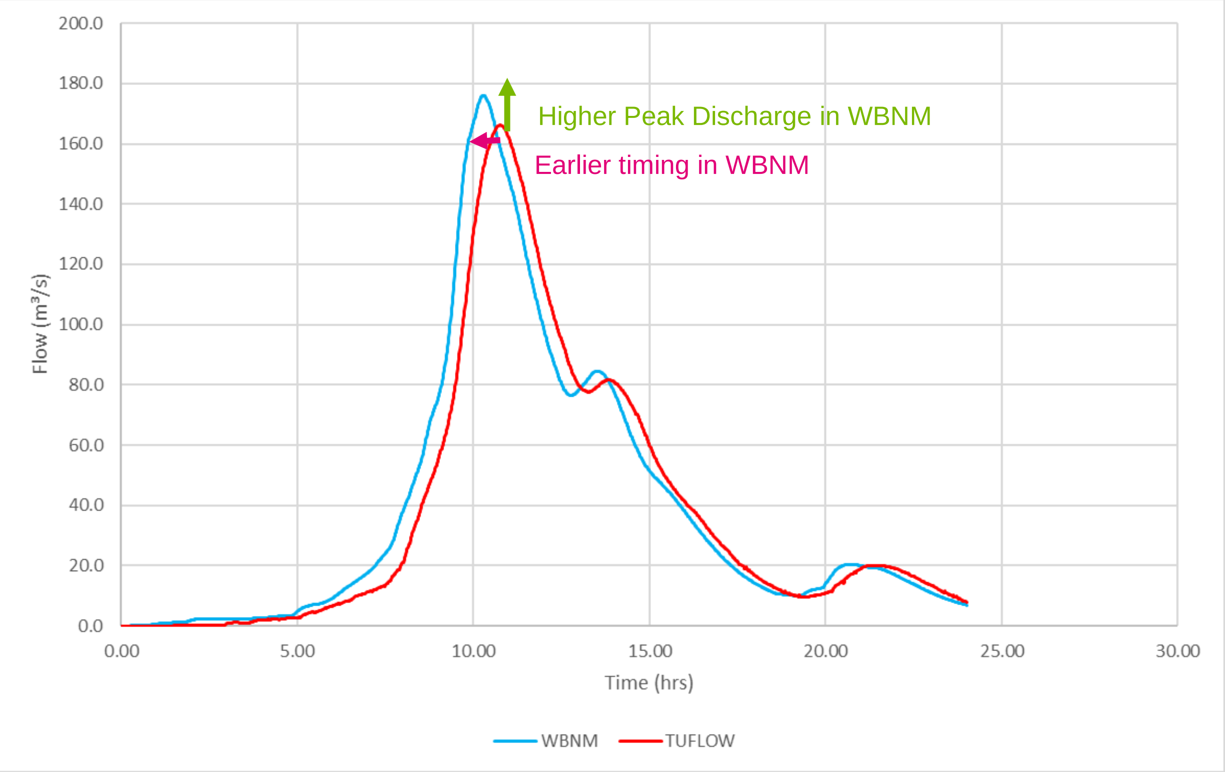

Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

Step 5: Create an artificial storage

Note: This step presents averaging of the storage curves of different ARIs at nominal outflow positions. BMT initially presented this approach to Council which provided good results, however the ‘averaging’ approach may require further refinement in areas with complex hydraulics during implementation (i.e. road crossings, tidal zones, off-river body storages).

To develop an artificial storage for the WBNM model, a table of the storages (S), and outflows (Q) is undertaken; the development of a S-Q curve. The S-Q curve requires calculations of storage at each timestep from both the TUFLOW and WBNM results. An optional H-Q curve, using water levels (H) at outflows (Q) can also be developed to indicate the water level at HEH points[6].

For this section, ‘outflow’ refers to the discharge results extracted from TUFLOW, and ‘inflow’ refers to the discharge results extracted from WBNM.

Develop the Storage-Outflow table

To develop the S-Q table, the following steps need to be undertaken:

1. Calculate the total accumulative storage for each timestep for all ARI and duration.
2. Construct the storage-outflow (S-Q) curves using the below calculations.

It is recommended to work from smaller magnitude ARI events towards the larger magnitude ARI events.

Step 5.1 Calculate the storage at each timestep

The following equation is used to calculate the total accumulative storage at each timestep:

$$\frac{1}{2}\Delta t\left((I_t + I_{t-\Delta t}) - (Q_t + Q_{t-\Delta t})\right) + S_{t-\Delta t} = S_t \qquad (1)$$

Where S_t is the storage to calculate at each timestep. The storage is calculated from the inflows simulated in the WBNM (I_t and $I_{t-\Delta t}$), outflows simulated in the TUFLOW (Q_t and $Q_{t-\Delta t}$), and the storage of the prior time step ($S_{t-\Delta t}$). Inflows and outflows are in cubic metres per second (m^3/s), storage is in cubic metres (m^3) and time is in seconds (s). An example of the calculation is shown in Figure 1.5. Additional notes to the calculation are as follows:

- Boundary conditions for the first timestep is zero for $I_{t-\Delta t}$, $Q_{t-\Delta t}$, and $S_{t-\Delta t}$.
- Timesteps between WBNM and TUFLOW need to be the same.

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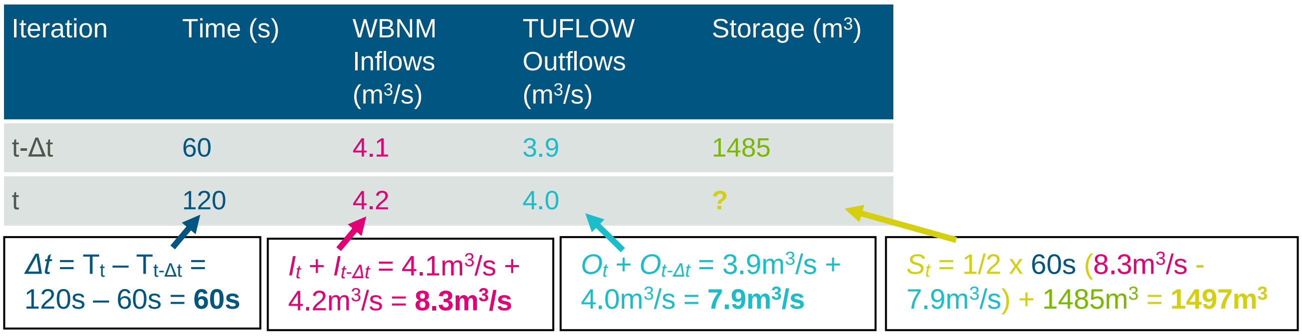
[6] H-Q curves are optional as the H in the HSQ curve is an incremental indicator within the WBNM software and can be applied as an ascending integer.



Iteration	Time (s)	WBNM Inflows (m^3/s)	TUFLOW Outflows (m^3/s)	Storage (m^3)
t-Δt	60	4.1	3.9	1485
t	120	4.2	4.0	?

$\Delta t = T_t - T_{t-\Delta t} = 120s - 60s = \mathbf{60s}$

$I_t + I_{t-\Delta t} = 4.1m^3/s + 4.2m^3/s = \mathbf{8.3m^3/s}$

$O_t + O_{t-\Delta t} = 3.9m^3/s + 4.0m^3/s = \mathbf{7.9m^3/s}$

$S_t = 1/2 \times 60s\ (8.3m^3/s - 7.9m^3/s) + 1485m^3 = \mathbf{1497m^3}$

Figure 1.5 Calculation of Storage

The ideal storage curve for each individual temporal pattern and ARI is where the storage increases with flow on the rising limb to the peak discharge[7]. Where this does not occur, the modeller should re-review the chosen stream lag factor in Step 3.

Step 5.2 Construction of the ideal storage-outflow curve

The ideal S-Q curve is developed from considering multiple S-Q curves for different ARIs and durations at nominal locations in the model. It is therefore a representative average S-Q curve for each point. It is envisioned that the 'ideal' S-Q curve can be developed using the following method:

- Extract the calculated storages in Step 5.1 from position points (herein referred to as 'nominal outflow positions') based on the outflow using either of the following methods:
  - the average storage of the rising and falling limbs of the S-Q curve for each duration of each ARI as shown in Figure 1.6 (developed using the ideal hydrographs in Figure 1.4), or
  - the storage of only the rising limb of the S-Q curve for each duration of each ARI (where the ideal hydrographs are not possible)
- Average the extracted storages across all ARIs at each nominal outflow position. It is recommended that a minimum of 3 individual storage calculations are used for the average.

  Figure 1.7 shows an example of the average S-Q curve across multiple durations and ARIs based on storages extracted from the rising limb (thick red line in Figure 1.7). BMT notes that there may be a trade-off between overestimating and underestimating the S-Q curve depending on duration or ARI. Hence, the averaging should preference the extracted storages from durations that align more closely with the critical duration at the HEH point (i.e. a HEH point with a critical duration of 1-hour should average durations from approximately 30 minutes to 2-hours).
- To extrapolate to a 0.05% AEP event and beyond, it is recommended that three durations with a peak discharge above the 0.05% AEP is simulated. Alternatively, a polynomial or linear trendline can be used to extrapolate to higher discharge. Figure 1.7 show a linear extrapolation of the average S-Q curve (shown as red dashed line).

The water levels (H) in the HSQ curves can be included using an ascending integer (0, 1, 2, 3, …) or developing a H-Q curve method described below.

BMT note that nominal outflow positions will need to be limited to the maximum lines allowed for the HSQ curve in WBNM.

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[7] Where storages do not increase in WBNM (the HSQ tables), the model produces erroneous results.

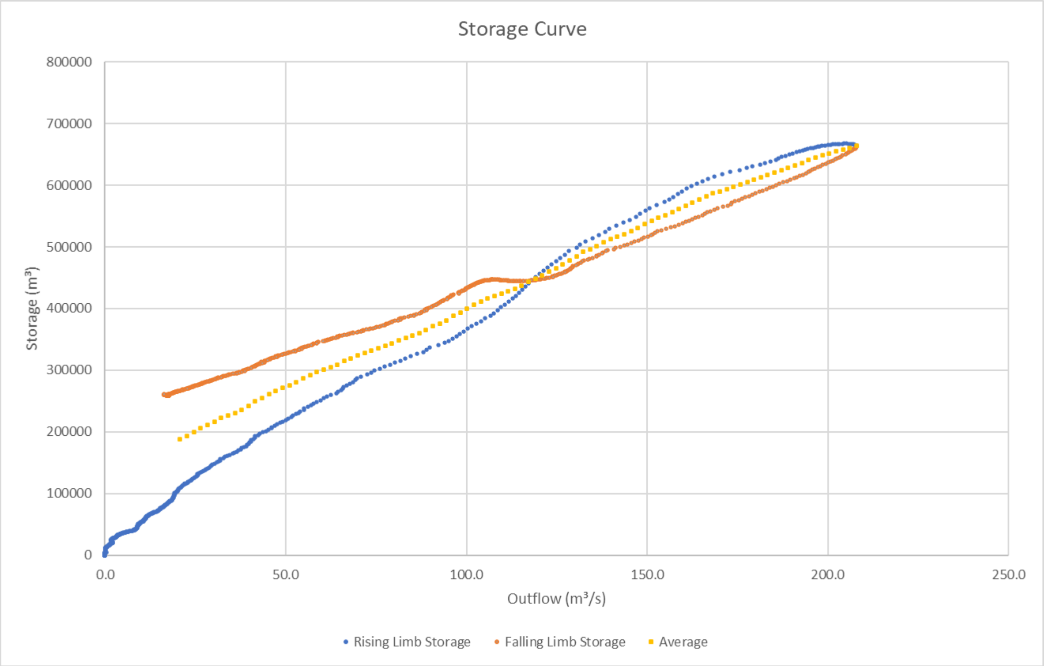
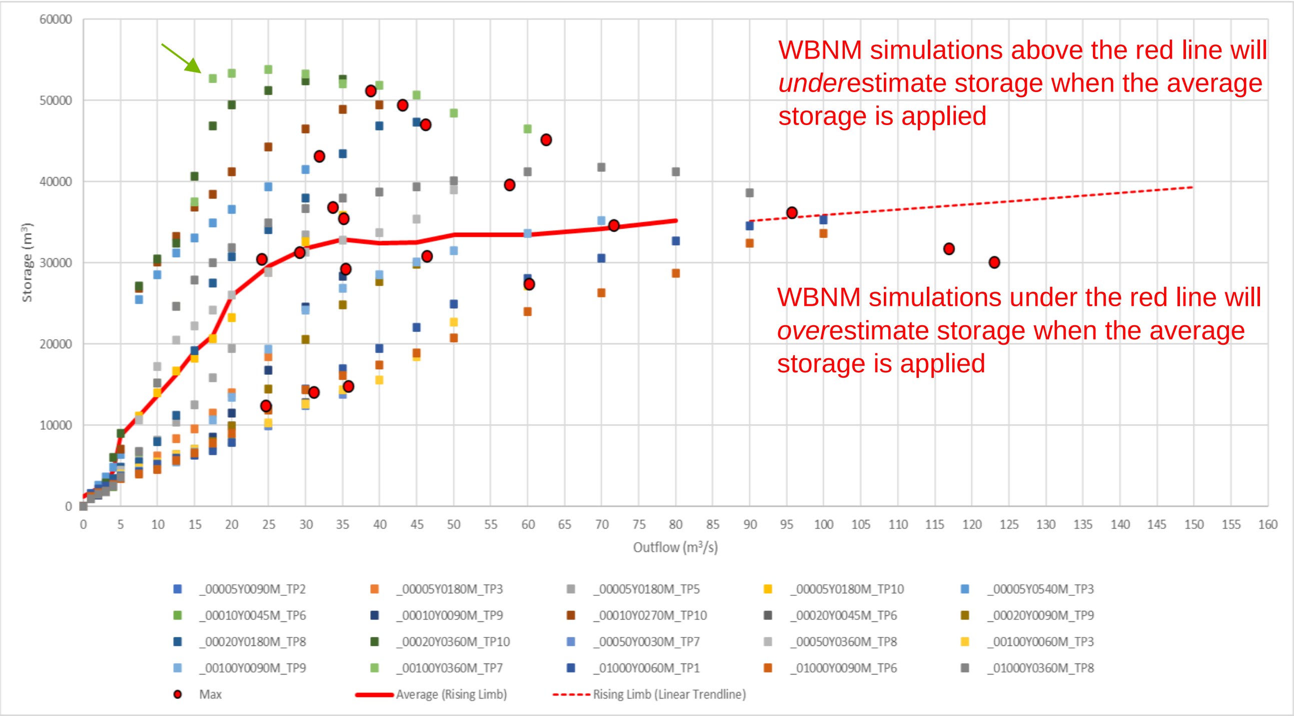


Figure 1.6 Ideal Storage-Outflow Curve

Light green dots result in
a curve which is not ideal



WBNM simulations above the red line will *under*estimate storage when the average storage is applied

WBNM simulations under the red line will *over*estimate storage when the average storage is applied

Figure 1.7 Example of an averaged S-Q curve (storages extracted from the rising limb of each duration and ARI)

Develop the HSQ rating curve (optional)

To extract water levels for the H-S-Q table, a rating curve of the water levels at the nominal outflow positions are extracted from the TUFLOW results. The ideal water levels would be the average of the rising limb and falling limb discharge for all simulated ARI events and durations as shown in Figure 1.8. The water level is then joined with the calculated S-Q table above using the nominated outflow positions.

It is noted that each rating curve should be reviewed for hysteresis. If notable hysteresis is present, caution will need to be taken when developing the H-S-Q table. In such circumstances, the H-S-Q table may require additional effort recognisiing that an ideal solution may not always be achieved.

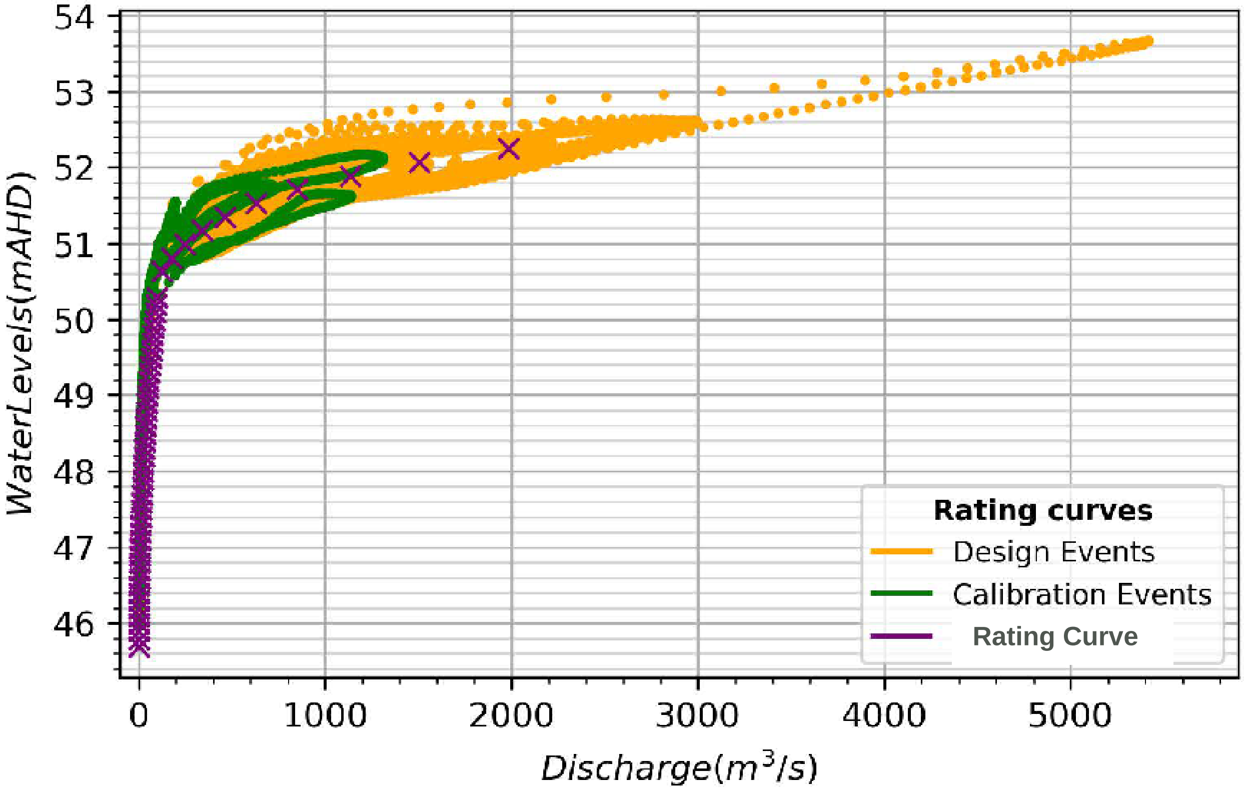


Figure 1.8 Rating curve with hysteresis

Implementation into WBNM

The developed HSQ table is placed into WBNM into the ‘Outlet Structures Block’. The required variables used for the implementation of the HSQ are listed in Table 1.2. The variables can be referenced from WBNM’s ‘runfile structure’ documentation (known as WBNM_Runfile.pdf).

Table 1.2 Outlet Structures Block Variables

HSQ Variables	Comment
DESCRIPTION_OF_OUTLET_STRUCTURE	
SUBAREA_NAME	HEH point name (should be the same as the sub-catchment specified in the TOPOLOGY BLOCK)
STRUCTURE_TYPE	HSQ
DISCHARGE_FACTOR BLOCKAGE_TIME (optional)	0
SUBAREA_TO_WHICH_FLOWS_ARE_DIRECTED	Same as that specified in the TOPOLOGY BLOCK for the HEH point
DIRECT_TO_TOP OR_BOTTOM_OF_SUBAREA	TOP
DELAY_OF_DIRECTED_FLOWS	0
NUMBER_OF_POINTS_IN_ELEVATION-STORAGE-DISCHARGE_RELATION	Number of nominal outflow positions. Limits may apply in WBNM.
Table of ELEVATION (metres) STORAGE_VOLUME (thousands m3) DISCHARGE (m3/s)	The developed HSQ curve at the HEH Point. Values should be ascending from the previous line.
INITIAL_WATER_LEVEL_IN_STORAGE	Same as lowest water level (H) from the HSQ curve
SURFACE_AREA	0
STORAGE_FACTOR	1