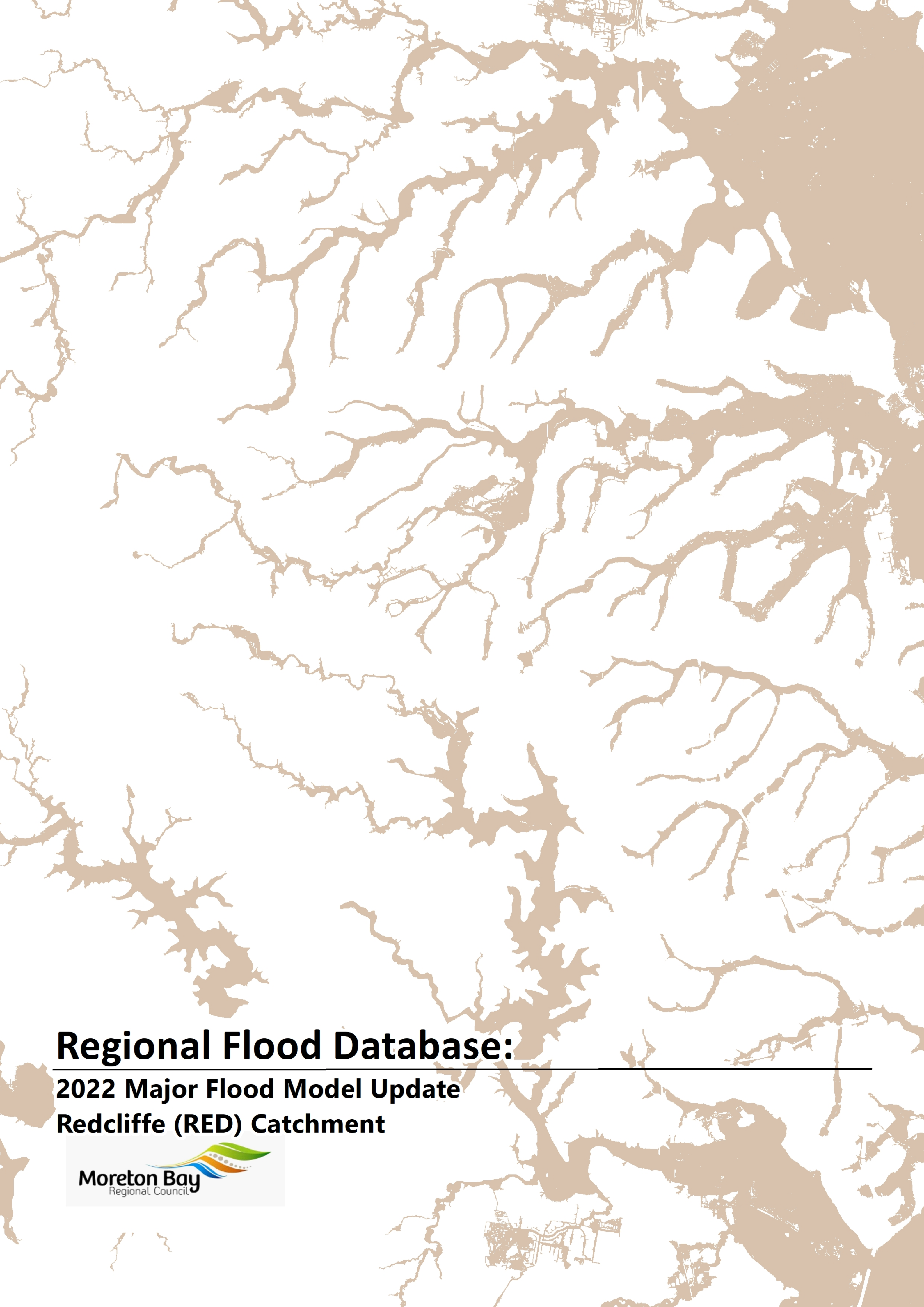

Regional Flood Database:

2022 Major Flood Model Update
Redcliffe (RED) Catchment

Document Status

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Client	Moreton Bay Regional Council
Client Project Manager	Hester Van Zijl
Water Technology Project Manager	Alister Daly
Water Technology Project Director	Tony McAlister
Authors	Donnie Carroll
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Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460
Fax (07) 3846 5144
ACN 093 377 283
ABN 60 093 377 283

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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 Redcliffe Catchment. Figure 1-1 presents the location of the Redcliffe 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 Redcliffe 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 Redcliffe Catchment.

2.1 Catchment Description

The Redcliffe 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 Redcliffe model domain with several individual tributaries draining north, south and east to Moreton Bay. The catchment has not been previously calibrated or validated to any historical data with no stream gauge data available.

The catchment is subject to inter-catchment flow which occurs mainly in rare flood events where overland flow dominates rather than underground trunk drainage.

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 Redcliffe 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 near the centroid of the catchment is presented in Table 3-1.

Table 3-1 ARR 2019 DataHub Parameters

Parameter	Value
Longitude	153.0975
Latitude	-27.2261
River Region	North East Coast
River Name	Pine River
ARF parameters	East Coast North
Storm Initial Losses (mm)	20
Storm Continuing Losses (mm/h)	2.4
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 and were used as the basis for the Redcliffe WBNM model. The only alteration to the subcatchments was undertaken near the Redcliffe Airport where both the TUFLOW and WBNM models were extended to the northwest. Figure 3-1 presents the changes to the WBNM model subcatchments.

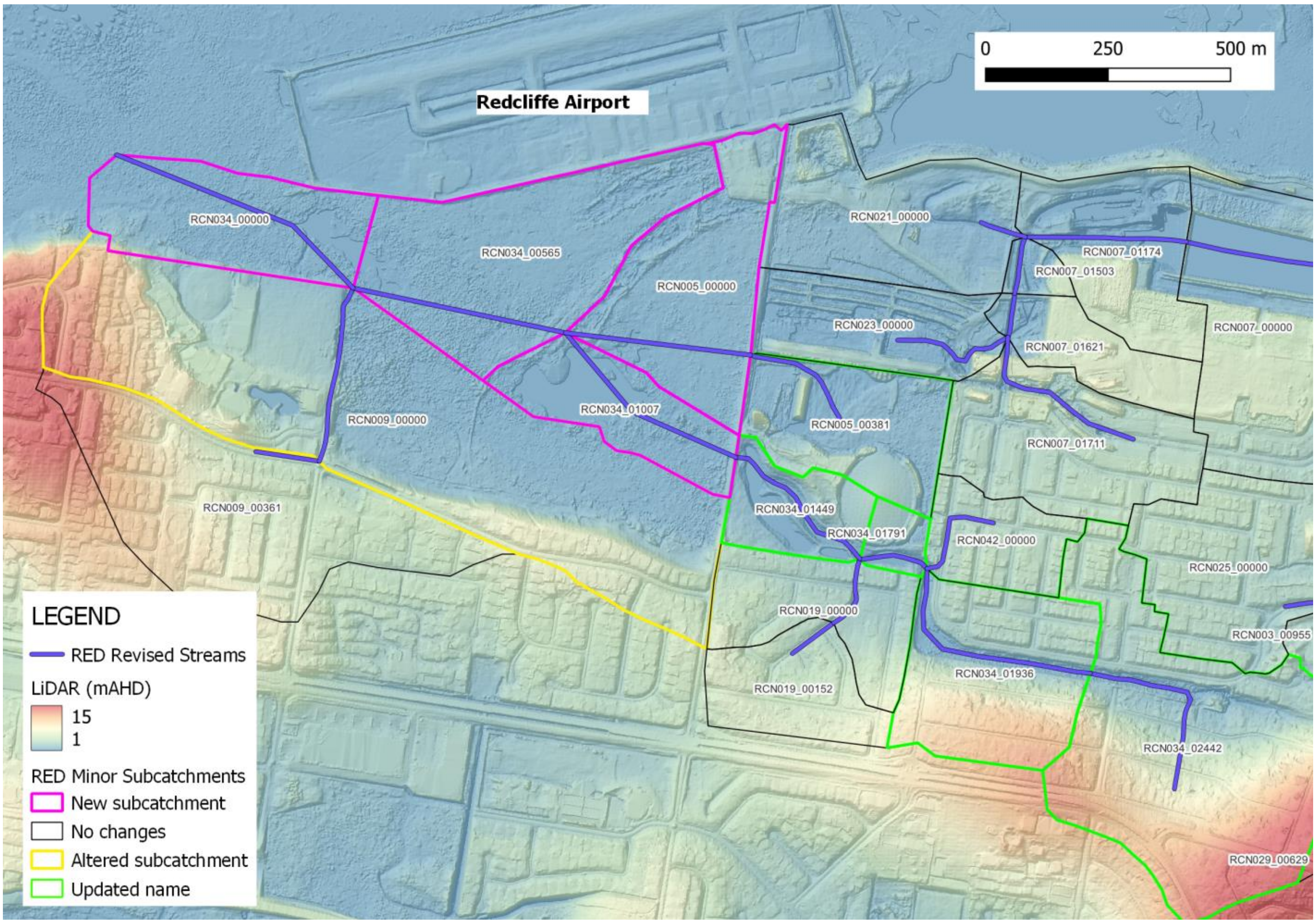


Figure 3-1 Redcliffe WBNM updated subcatchments

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 Redcliffe 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 historical events 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 Redcliffe model. It is noted that the area ranges are slightly different to the other RFD catchments as the Redcliffe catchment is insensitive to ARFs given the majority of catchments do not require any reduction as they have an area less than 1km^2. 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	# of POIs in class	Area Range (lower to upper bounds)	Applied Area (Storm Injector)	Temporal Pattern Applied
ARFa	19	0km^2 to 1.7km^2	None, ARF = 1	Point
ARFb	4	1.7km^2 to 7.8km^2	2.5km^2	Point

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 20 mm Initial Loss and 2.4 mm/hr Continuing Loss. This is consistent with neighbouring RFD catchments.

3.4 TUFLOW Hydraulic Model Update

To assess the hydraulic characteristics for the Redcliffe 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 Redcliffe 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 Redcliffe 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 Redcliffe area. The code boundary extent has been modified from the previous study to accommodate additional inflow locations and trunk drainage networks. Figure 3-3 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 topographic data supplied by MBRC includes the 2019 1m LiDAR data set which represents the most current topographical data available for the catchment. The data was supplied as a 1m Digital Elevation Model (DEM) raster which was used to inform all model development tasks undertaken for this study. The LiDAR data covers the full extent of the Redcliffe catchment and is suitable for the purposes of this study. 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.

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. Additional localised DEMs were also provided by MBRC 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 and the Langdon Park wall has been added from the provided survey. Gully lines along creek channels were updated with the latest 2019 topography where lower than previously enforced gully line values. In general, the previous gully lines were lower than the 2019 LiDAR with the only changes required near the Redcliffe racecourse where the 2019 LiDAR was significantly lower than the adopted gully lines.

Observations from the site visit noted challenges in modelling several small urban channels throughout the Redcliffe region using a 5m fixed grid. Figure 3-2 presents a 4m wide typical channel observed throughout the catchment. To represent this in the model a thin gully line has been applied to ensure conveyance is not overestimated using 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 Redcliffe RFD revisions would be a finer grid cell size or application of Sub-Grid Sampling (SGS).

Figure 3-2 Open channel along Bellevue Terrace observed on site visit, 24th March 2022

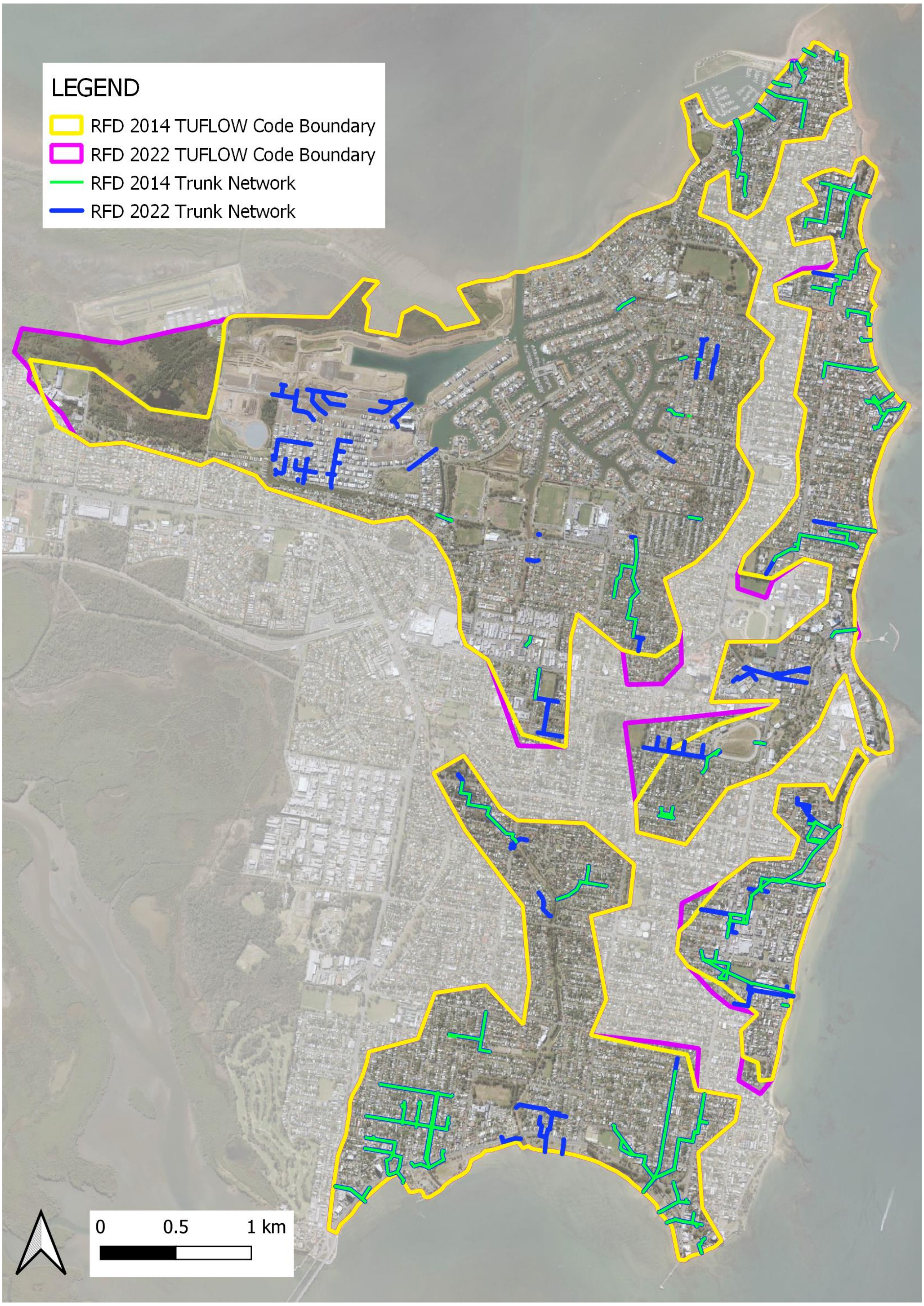


Figure 3-3 Hydraulic model extent change

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 (layered flow constriction) 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 whilst with this update a value of 1.6 has been adopted through the structures deck.

On the site visit several pedestrian bridges were observed which were not in the provided MBRC structure database. These have been added to the updated TUFLOW model. With the lack of structure details available several assumptions have been made. Figure 3-4 presents an example of a bridge near Kr Benson Park and the subsequent 2d_lfcsh attributes applied to a line shape layer.

Invert	99999.00000
dZ	NULL
Shape_Widt	NULL
Shape_Opti	NULL
L1_Obvert	1.70000
L1_pBlocka	5.00000
L1_FLC	0.05
L2_Depth	0.35
L2_pBlocka	100.00000
L2_FLC	1.60000
L3_Depth	1.00000
L3_pBlocka	50.00000

Figure 3-4 Pedestrian bridge near Kr Benson Park observed on site visit, 24th March 2022

A key structure in the catchment is the Minimum Energy Loss (MEL) structures underneath Redcliffe Drive which allow water flowing in Humpy Bong Creek to discharge to the bay. The configuration is unable to be modelled accurately using the TUFLOW shallow water equations. Therefore, the available computational fluid dynamic (CFD) modelling results should be used to verify the results of the TUFLOW model. An extract of the rating curve generated from the CFD modelling is provided in Figure 3-5.

To account for the reduced losses of the physical structure, the inlet and outlet losses of the culvert structure in TUFLOW were reduced to zero. This alteration combined with removing the automatic manholes produced previously with the culvert separated at the junctions, reduced the modelled peak water levels to levels similar to that indicated by the CFD modelling. Furthermore, these changes improved the model correlation to the observed debris marks in the February 2022 validation event (see Section 4).

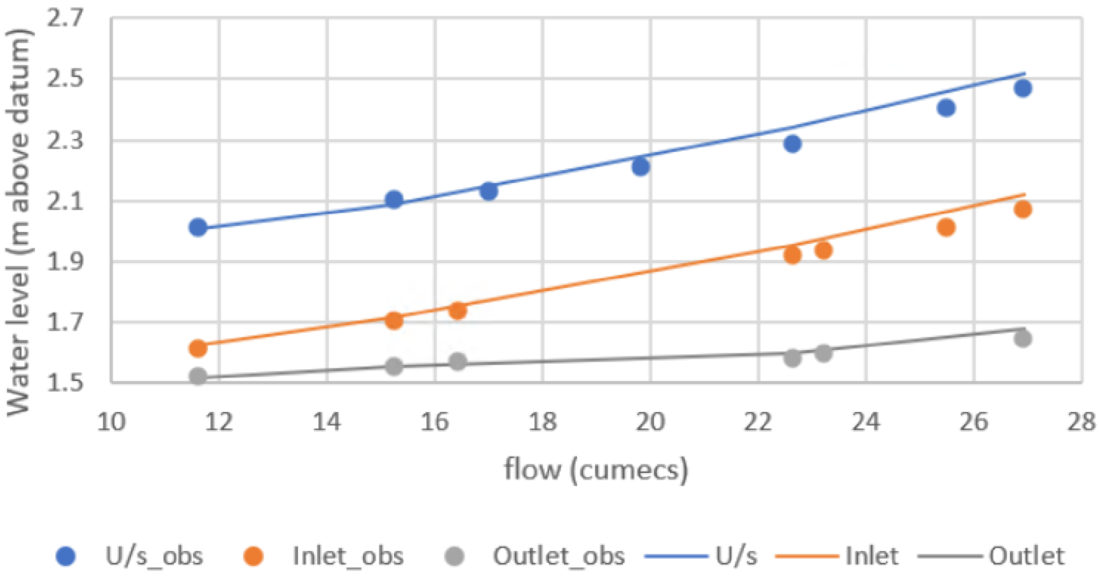


Figure 3-5 **Extract of rating curve from CFD memo for Humpy Bong Creek culverts under Redcliffe Parade**

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. Redcliffe is unique in that pits have been modelled as 0.9 mx0.6 m R type nodes and the number of pits is estimated as the number of upstream pits in the wider stormwater network. This approach has been maintained for all new and existing trunk networks. The default pit (with no consideration of upstream pits) is modelled as 2/0.9mx0.6m R type 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 3-8 illustrates the stormwater pipes and culverts included in the updated hydraulic model.

3.4.3.3 Other Structures

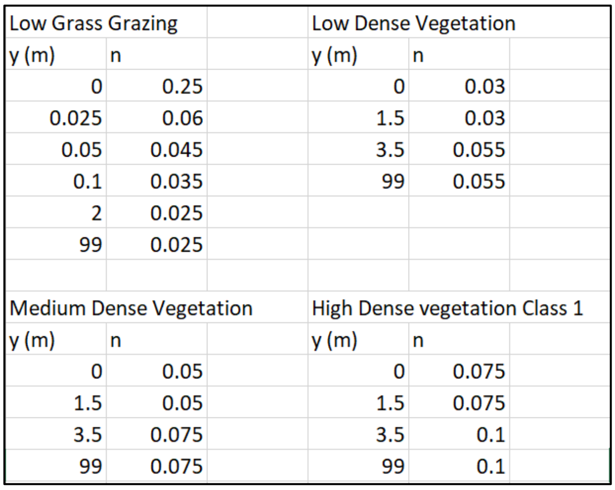
There were no fauna fences requiring modelling within the Redcliffe catchment as per the provided GIS files. The guardrail located at the Humpy Bong creek crossing of Anzac Avenue has been modelled with all other guardrails in the region being outside of the 2014 model PMF flood extent. The guardrail has been modelled as per the TMR hydrologic and hydraulic guidelines (2019) as a 2d_lfcsh line layer. An assumption of a 400 mm depth to the underside of the W beam and a 350mm depth of cross-member has been assumed without the specific guardrail drawings being available for reference.

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 3-6 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 3-7 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 3-6 Depth varying Manning's values

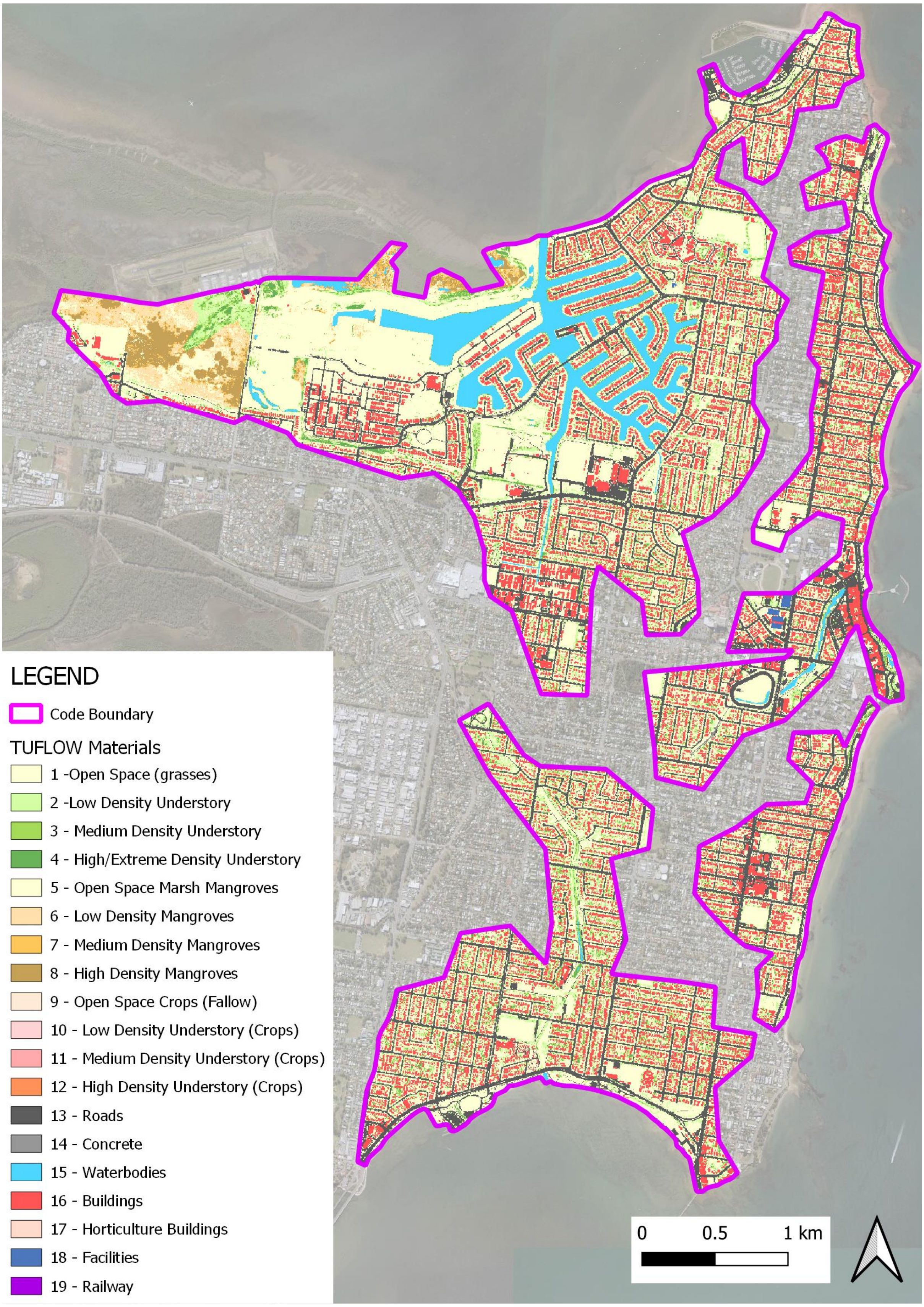


Figure 3-7 Hydraulic model roughness layout

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 3-8. 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 in subsequent stages of this study.

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.

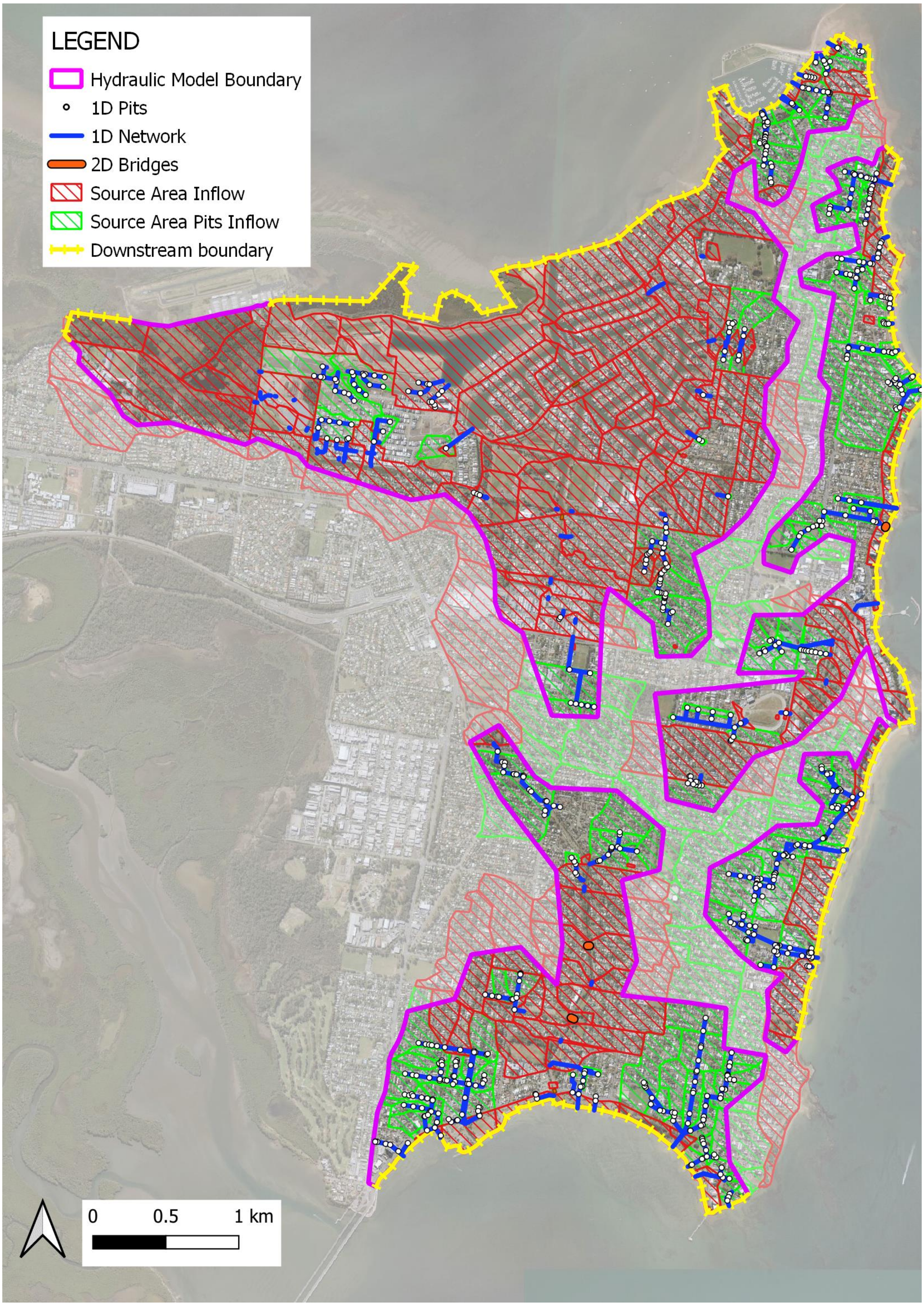


Figure 3-8 Hydraulic model trunk network and inflow boundaries

4 MODEL METHODOLOGY AND SIMULATIONS

4.1 Validation to Historical Events

There are no available stream gauges within the Redcliffe 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
November 2014	6	27/11/2014 11:55 AM	29/11/2014 06:00 AM
February 2022	19	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
Kippa-Ring	540629	Nov2014/Feb2022
Woody Point	540498	Nov2014/Feb2022
Rothwell (Anzac Ave) Alert	540659	Nov2014/Feb2022

4.1.2 Stream Gauge Data Available

There are no stream gauges available within the Redcliffe 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 events. 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
November 2014	16	7
February 2022	20	19

4.1.4 Tidal Levels

A tidal boundary for the Redcliffe 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 Redcliffe areas. The November 2014 event was less sensitive to tidal levels as was a 1 hour duration storm and therefore a fixed tailwater was adopted.

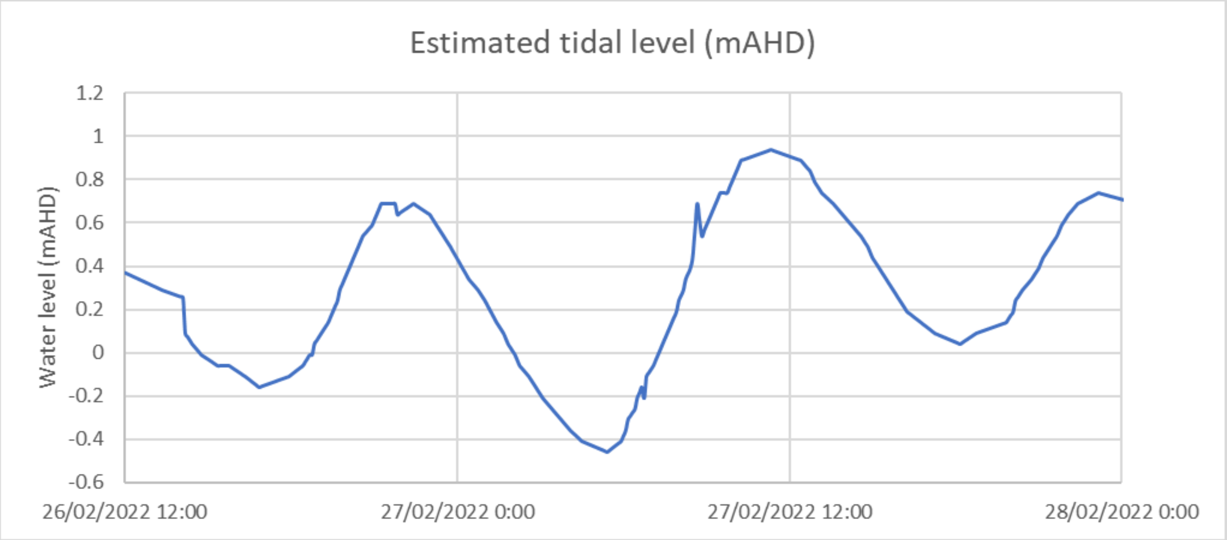


Figure 4-1 Estimated dynamic tailwater level applied to February 2022 Validation event

4.1.5 Losses and Catchment Parameters

Table 4-4 presents the adopted Initial and Continuing Loss values for the respective validation events across the Redcliffe 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.

Table 4-4 Validation events - WBNM adopted parameters

Catchment	Event	Catchment Lag Parameter	Initial Loss (mm)	Continuing Loss (mm/hr)
Redcliffe	2014	1.6	10	2.5
	2022		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 Redcliffe 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 23 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 Redcliffe with several access roads in and out of the main developed areas in Redcliffe.
    - Inflow locations to canal systems (Newport marina).
    - Obtaining a spread of ARFs throughout the catchment – this also involved selecting “typical” Redcliffe catchments. It was noted there are several small Moreton Bay draining catchments which have similar catchment features (landuse, area etc) and therefore only one (1) of these catchments was selected noting that the critical duration and ARF will be applicable to similar catchments.

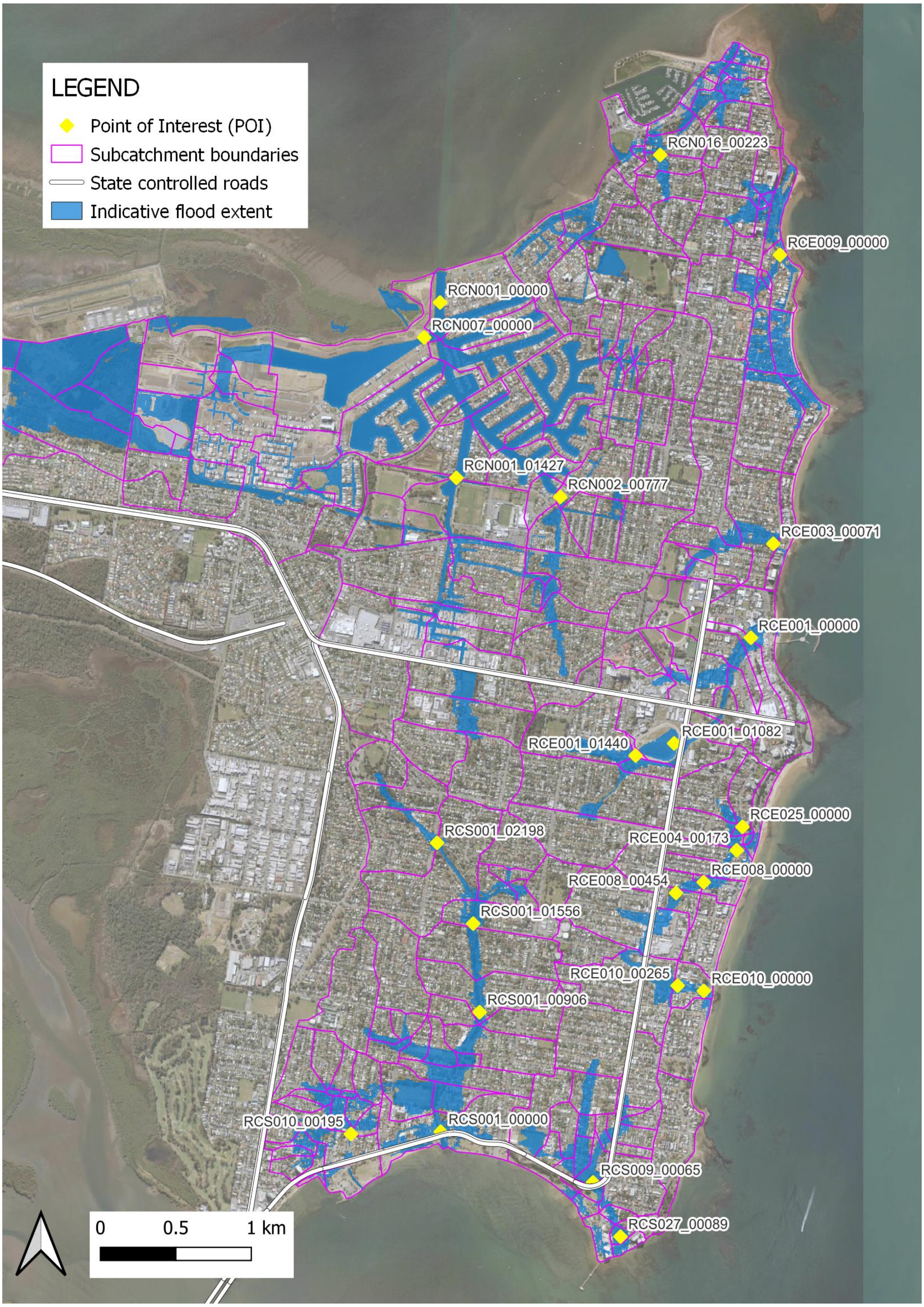


Figure 4-2 Redcliffe Point of Interest locations

4.2.2 Methodology

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

- Simulated 3 different design flood events – 10%, 1% and 0.05% Annual Exceedance Probability (AEP). For each event both the 60-minute and 180-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 2014 RFD Redcliffe flood study.
- For each POI a comparison of hydraulic (TUFLOW) and hydrologic (WBNM) models was undertaken. The initial approach to achieve joint calibration at the POI was to alter the stream routing parameters within the WBNM model. 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.
- 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 then 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 Redcliffe catchment is unique in that it is heavily urbanised with complex hydraulic interactions as a result of significant trunk stormwater pipe networks and canal systems. For these reasons the HEH methodology has limitations in its application throughout the catchment and in some circumstances the criteria have not been able to be met despite significant model testing and iteration.

4.3 TUFLOW Hydraulic Model

4.3.1 Adopted Design Tailwater Conditions

A static tailwater of 0.83 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 Redcliffe 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 November 2014

Figure 5-1 presents the spatial map of the hydraulic model validation when comparing the TUFLOW model results to the surveyed flood depths for the November 2014 event. Appendix A includes a histogram of the debris mark differences. There is very limited data available for the November 2014 event with only 7 marks for validation although all results were within 400 mm of the recorded levels. In the context of the isolated storm event and the relatively small magnitude of the storm overall, the hydraulic model has performed reasonably well in matching the observed flood marks.

5.1.2 February 2022

Figure 5-2 presents the spatial map of the hydraulic model validation when comparing the TUFLOW model results to the surveyed flood depths for the February 2022 event. Appendix A includes a histogram of the debris mark differences. Overall, the hydraulic model has performed reasonably well in matching the observed flood marks. Approximately 35% of the markers were within 100mm and approximately 45% of the modelled depths were within 300mm of the measured levels.

Considering the uncertainty of the hydrologic modelling without any stream gauge calibration these results are encouraging and suggest that adoption of the parameters for the hydrologic model is valid. There was a pattern noted on the eastern side of the island with the TUFLOW model over estimating flood levels. It is hypothesized that this is due to the rainfall of Kippa-Ring Alert being extremely intense that there would have been significant spatial variation in the rainfall which has not been captured using two discrete gauge locations. The flood levels estimated along Bells Creek were very accurate which is most likely attributed to good rainfall coverage in the upper catchment at Kippa-Ring Alert and in the lower catchment at Woody Point Alert.

Acknowledging the spatial uncertainty of the rainfall, a thorough investigation into the hydraulics of Humpy Bong Creek was also completed where the model showed significant overestimation of peak water levels across the entire creek. The box culverts at the Redcliffe Business CBD are a key structure and flood levels along the creek are sensitive to its performance. As discussed in Section 3.4.3, the inlet and outlet losses were reduced to improve validation performance in this location.

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 has added significant confidence that the Redcliffe WBNM model is representing the catchments hydraulic response (where possible) through alteration of stream routing parameters and the addition of artificial storage curves. Six (6) out of the 23 POI locations required artificial storage curves added into the WBNM model. Twelve (12) out of the 23 locations were noted to not have met the HEH criteria for all the simulated events. For these locations, justification has been provided with a description of the complex hydraulics unable to be modelled in the simplistic WBNM runoff routing model.

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, the HEH model is suitable to inform design event storm selection and could be utilised in the context of flood forecasting.

Figure 5-1 Redcliffe November 2014 – extent and debris map

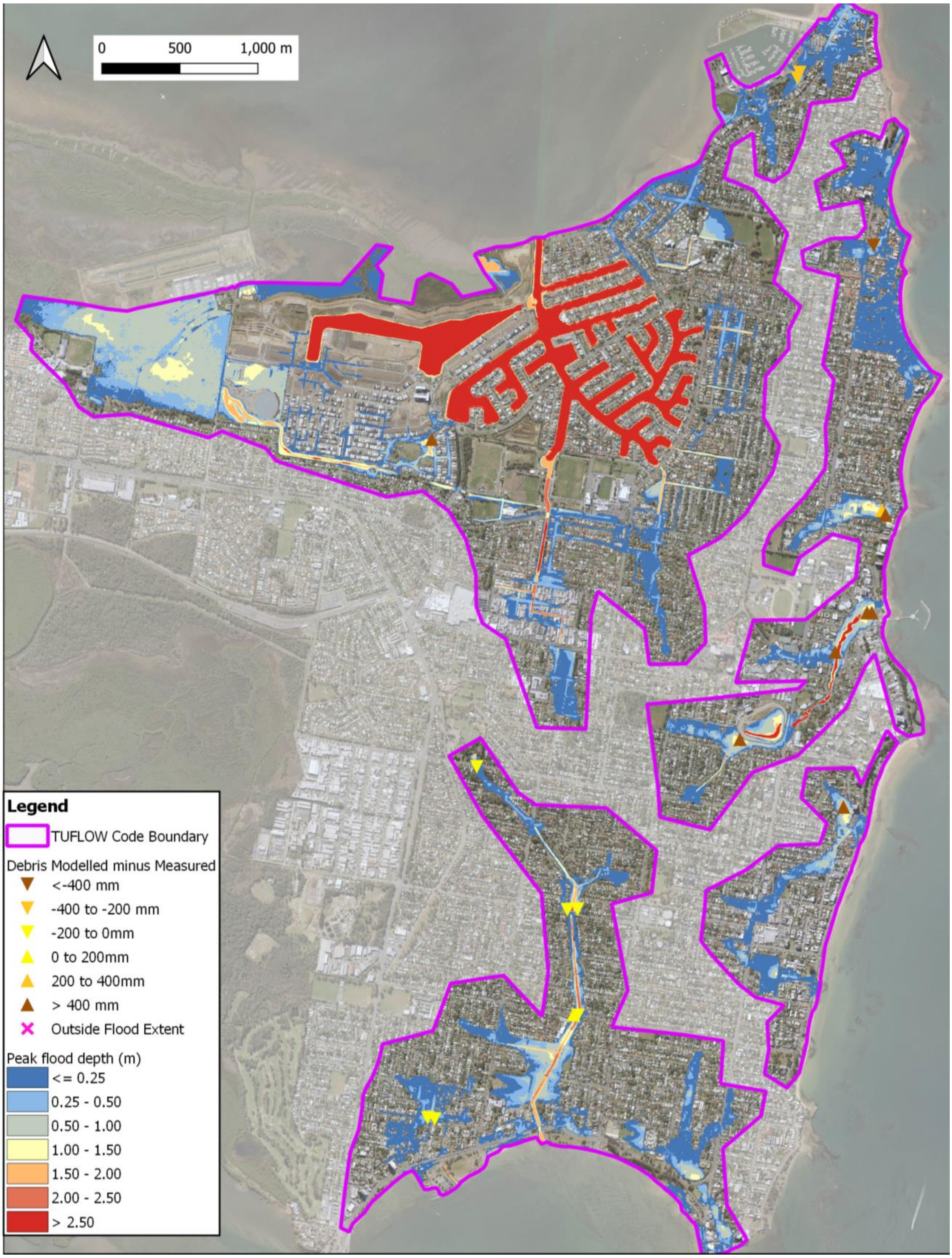


Figure 5-2 Redcliffe February 2022 – extent and debris map

5.2.1 Critical Storm Selection

Table 5-1 presents the selected storm events simulated in the TUFLOW model. The storms were selected using the HEH model where critical storms were selected at POIs. Not all storms were simulated hydraulically with only the dominant storms selected. Furthermore, where several temporal patterns were critical for a certain durations across the POIs only 1 temporal pattern was selected and it was checked to ensure that a significant over or underestimation would not occur at other POIs. The source grids of the envelope results were analysed and these did not identify any single storm event which dominated the envelope grids across the AEPs.

Table 5-1 Critical events selected

AEP	ARFa	ARFb
20%	30min_TP09, 60min_TP04, 180min_TP05, 270min_TP04	120min_TP08
10%	30min_TP09, 45min_TP06, 60min_TP07, 360min_TP01	120min_TP06
5%	20min_TP05, 45min_TP06, 60min_TP06, 360min_TP01	120min_TP05
2%	30min_TP01, 45min_TP05, 90min_TP03, 360min_TP06	120min_TP02
1%	30min_TP01, 45min_TP05, 90min_TP06, 270min_TP02	120min_TP02
1in1000	30min_TP08, 45min_TP05, 90min_TP03, 270min_TP08	120min_TP06
1in2000	30min_TP02, 45min_TP05, 90min_TP03, 270min_TP08	120min_TP06

5.3 Design Flood Behaviour

5.3.1 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 5-2 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 5-2 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
RCE001_01082	90	TP09	21.9	90	TP06	21.7
RCE001_01440	90	TP06	23.6	90	TP06	23.4
RCE003_00071	90	TP05	20.2	90	TP06	19.7
RCE004_00173	90	TP06	4.0	90	TP06	5.3
RCE008_00000	90	TP03	14.8	45	TP05	13.1
RCE008_00454	90	TP06	10.6	45	TP05	10.4
RCE009_00000	45	TP05	10.5	45	TP05	10.8
RCE010_00000	90	TP06	11.2	90	TP06	10.1
RCE010_00265	90	TP06	10.0	90	TP06	10.0
RCE025_00000	90	TP03	6.8	45	TP05	6.7
RCN002_00777	90	TP03	25.8	45	TP05	26.1

POI	WBNM Duration (min)	WBNM Adopted TP	WBNM Peak flow	TUFLOW Duration (min)	TUFLOW Adopted TP	TUFLOW Peak flow
RCN007_00000	270	TP02	10.7	90	TP06	10.2
RCN016_00223	45	TP06	5.8	45	TP05	5.9
RCS001_00906	90	TP06	44.4	90	TP06	41.9
RCS001_01556	90	TP06	33.9	90	TP06	33.0
RCS001_02198	90	TP03	11.6	45	TP05	10.9
RCS009_00065	90	TP09	16.6	90	TP06	16.8
RCS010_00195	90	TP05	7.9	90	TP06	8.2
RCS027_00089	30	TP01	0.6	90	TP06	3.4
RCE001_00000	120	TP02	35.4	90	TP06	33.4
RCN001_00000	90	TP05	156.4	90	TP06	164.6
RCN001_01427	90	TP03	62.2	90	TP06	66.2
RCS001_00000	90	TP05	68.2	90	TP06	61.4

5.3.2 Comparison to RFD 2014

Figure 5-3 presents the difference in peak flood level between the RFD 2022 (this study) and the previous RFD 2014 peak flood level across the catchment (both unblocked scenarios). In general, the peak flood levels are lower than the previous study with reductions of up to 200 mm. This reduction is 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 5-4 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 are reduced although less than the existing climate results. In certain locations such as Clontarf, flood levels have increased by up to 300 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. It is noted that RFD 2014 did not incorporate blockage into the catchment.

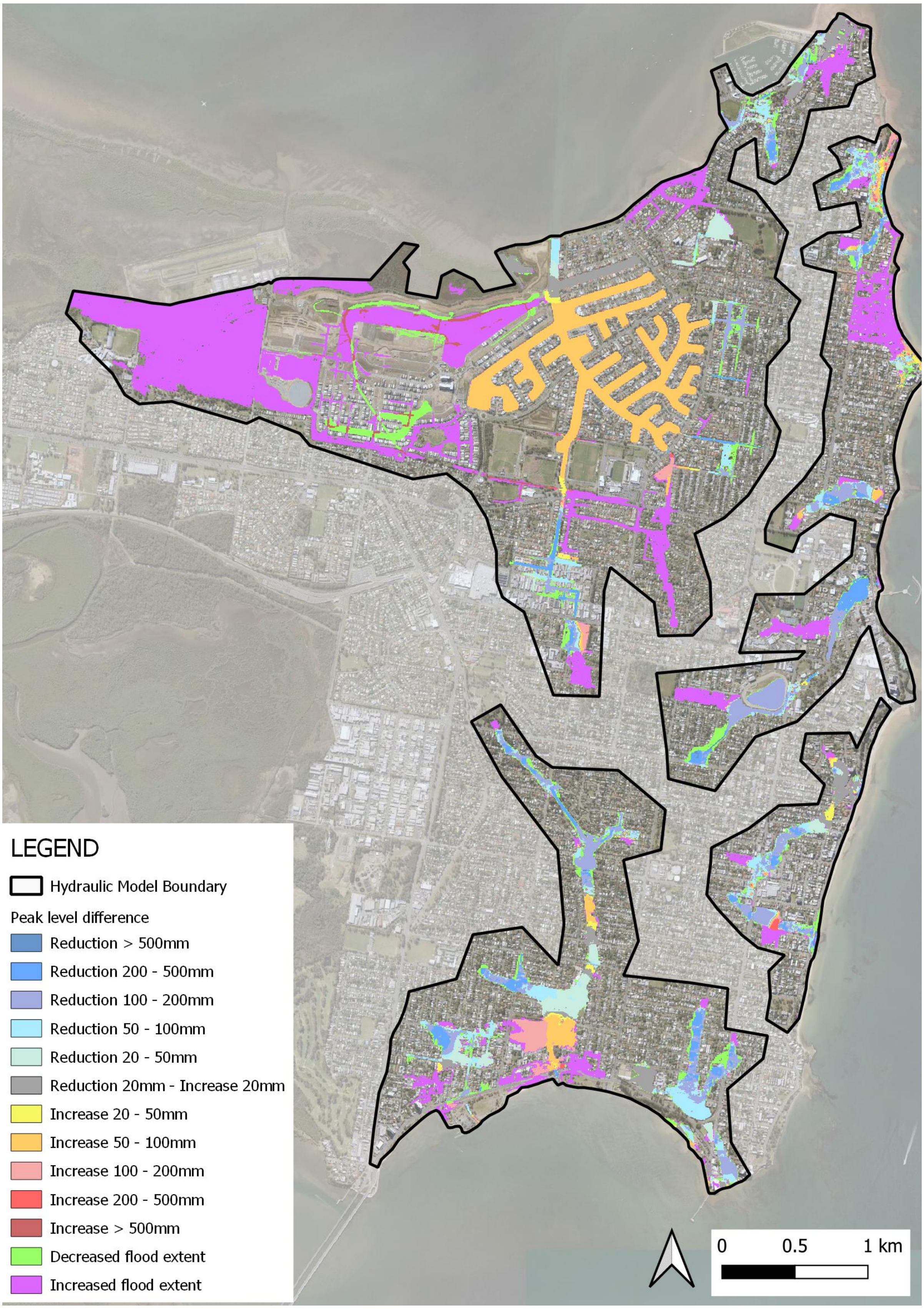


Figure 5-3 RFD 2022 minus RFD 2014 1% AEP peak flood level (unblocked)

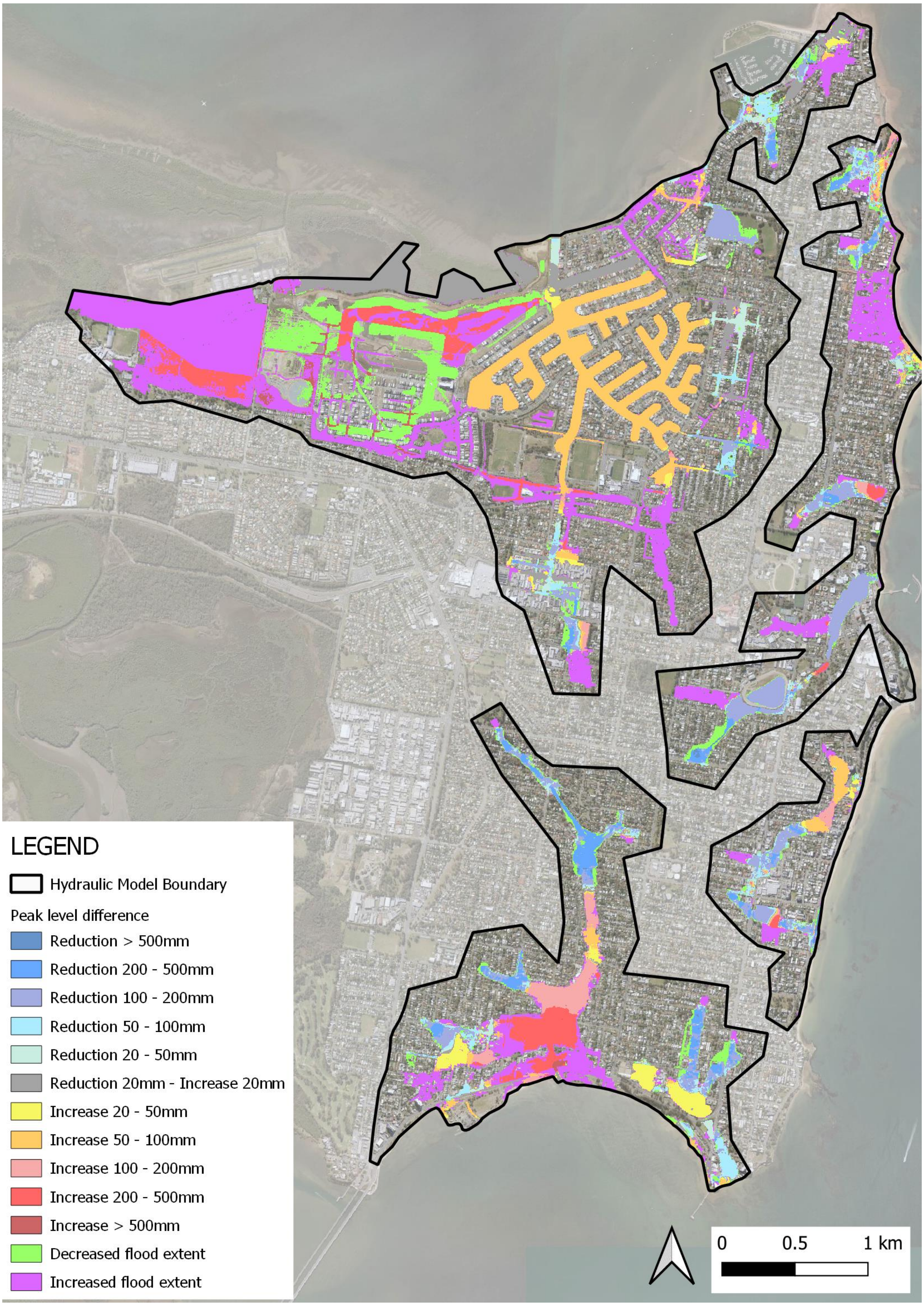


Figure 5-4 RFD 2022 minus RFD 2014 1% AEP DFE peak flood level (future climate)

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 0.45 which is approximately 1/10th of the cell size (see Figure 5-5). 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 Redcliffe catchments were represented in the 2D domain, for which the grid resolution is limited to 5m. 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.

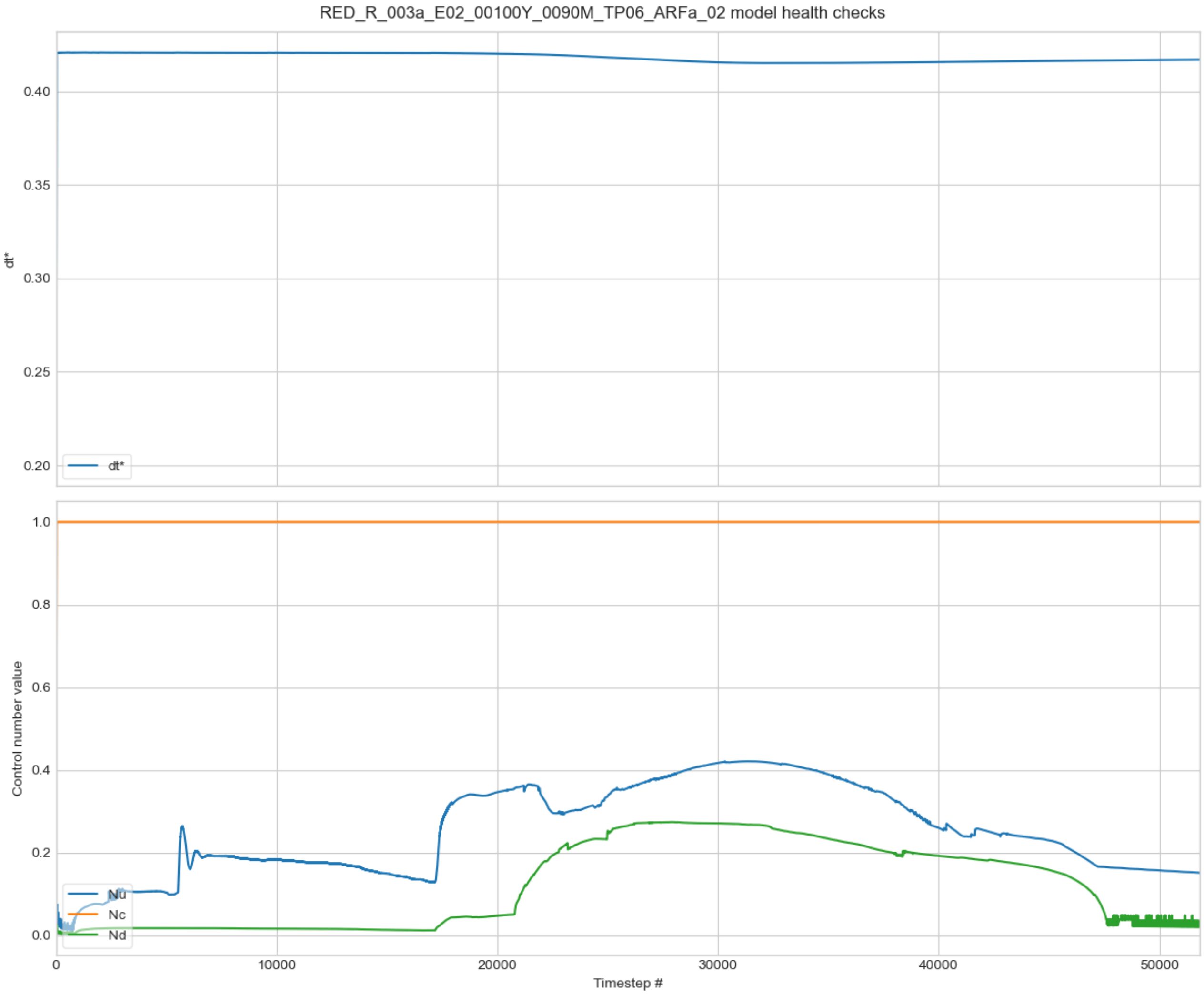


Figure 5-5 TUFLOW model health check

5.5 Model Specification and Run Times

Redcliffe is one of the smaller catchments within the MBRC RFD study area, encompassing 15.9 km^2 and 2,520,000 grid cells (at 5m cell size). Table 5-3 provides a summary of the Redcliffe TUFLOW model specification and run times. It is noted that runtimes will vary depending on CPU and GPU hardware used.

Table 5-3 Redcliffe model specification and run times

Event	Model run time (hours) (varies per duration)	Startup Memory (MB)	GPU memory required (MB)
20% AEP (120min)	0.3	1000	522
1% AEP (90min)	0.3		
1 in 2000 AEP (120min)	0.4		

6 CONCLUSION

As part of the Stage 4 and 5 update of the RFD for Redcliffe, 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 Redcliffe 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 Redcliffe 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 Redcliffe 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 Redcliffe catchment representing a significant improvement over previous iterations. As previously outlined in this report, there are limitations in the adopted 5 m cell size in the hydraulic model to represent the smaller channels throughout the urbanised Redcliffe 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 Redcliffe 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 Redcliffe 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 models parameterisation and the resulting design flood level outputs.

8 REFERENCES

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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 November 2014

Hydrological data from the rainfall stations at Woody Point and Kippa-Ring Alert were utilised to generate the spatial distribution of rainfall in the November 2014 event (see Figure 8-1). Rainfall was distributed using the standard WBNM method which assigns rainfall depths to each subcatchment based on a weighted average depth calculated using the nearest pluviograph station data. The weights are calculated based on the inverse square of the distance between the pluviography station and the sub-area centroid. The event was very localised around the south-eastern portion of the Redcliffe peninsula and the rainfall only lasted for approximately 3 hours in total duration. The peak 1 hour intensity was 26 mm/hr which correlates to less than a 50% Annual Exceedance Probability (AEP) event. The total rainfall recorded at the Woody Point Alert gauge for the event was 61 mm.

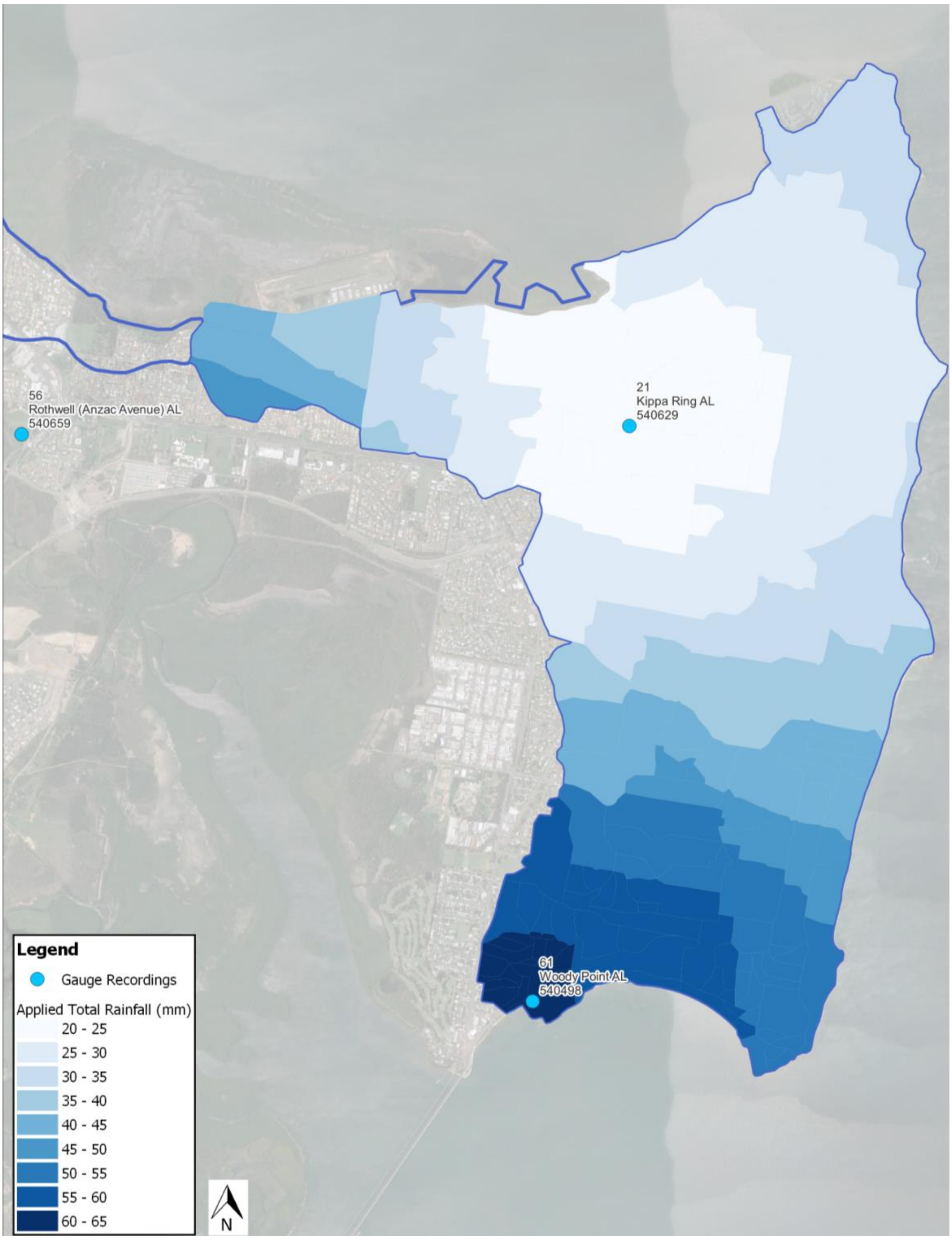


Figure 8-1 Redcliffe WBNM subcatchment rainfall totals – November 2014

A-1-2 February 2022

Hydrological data from the rainfall stations at Woody Point and Kippa Ring Alert were utilised to generate the spatial distribution of rainfall in the February 2022 event. Figure 8-2 and Figure 8-3 present the cumulative and sub-daily rainfall plots for the Kippa-Ring and Woody Point Alert rainfall stations respectively. Available information indicates that over 1,000 mm of rainfall occurred at the Kippa-Ring and Woody Point Alert 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 8-4 presents the WBNM subcatchment spatial distribution of total rainfall for the event.

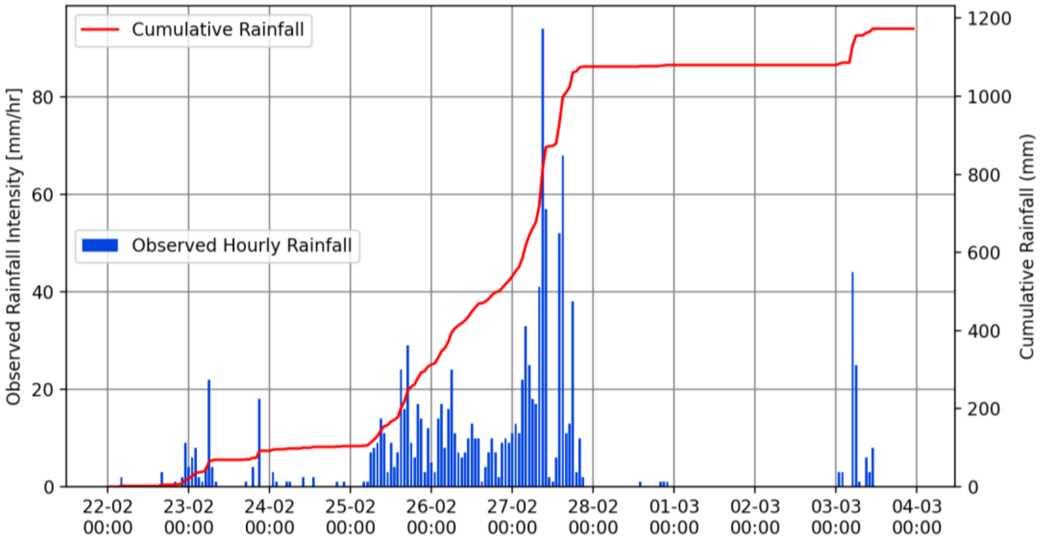


Figure 8-2 Cumulative and sub-daily rainfall plot for Kippa-Ring Alert

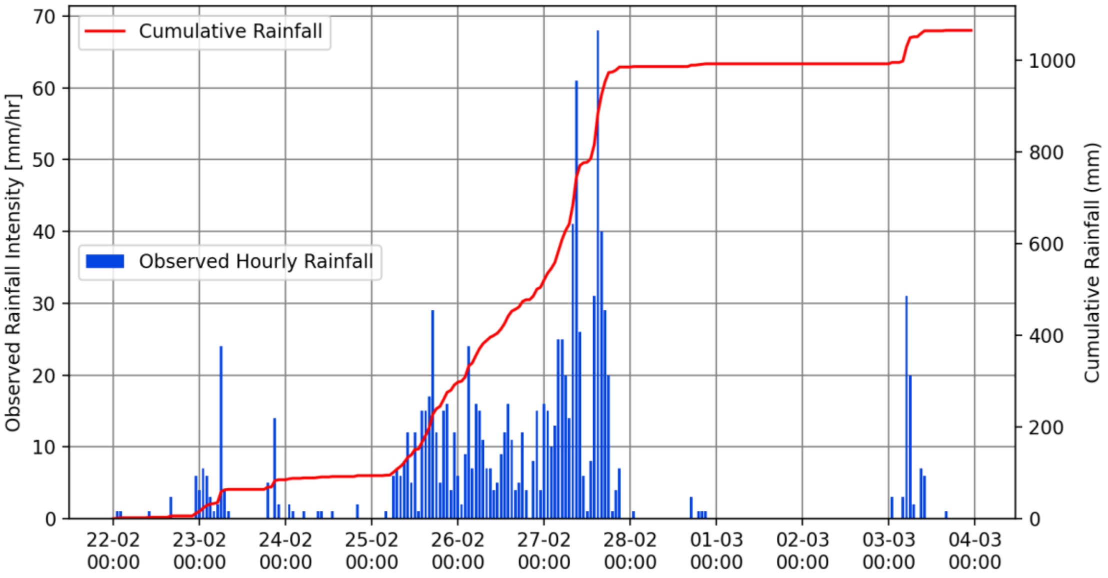


Figure 8-3 Cumulative and sub-daily rainfall plot for Woody Point Alert

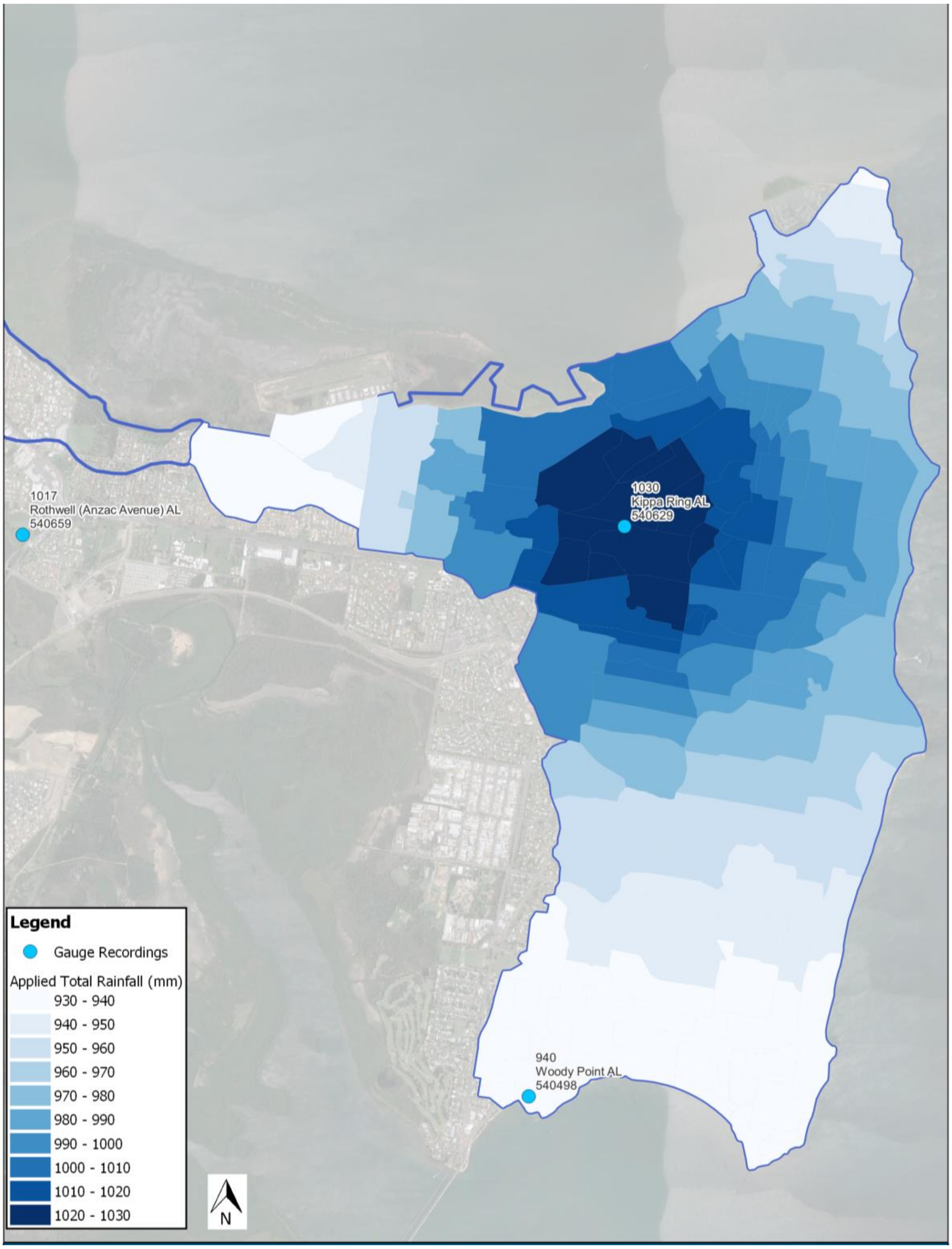


Figure 8-4 Redcliffe WBNM subcatchment rainfall totals – February 2022

Figure 8-5 shows the recorded rainfall intensities and their estimated Annual Exceedance Probability (AEP) at the Kippa-Ring Alert (540629) and Woody Point Alert (540498) 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 Kippa-Ring Alert, the data indicates the following:

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

For Woody Point 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 of about 1%; and
- Storm durations of 12 hours and longer had an AEP greater than 1 in 500.

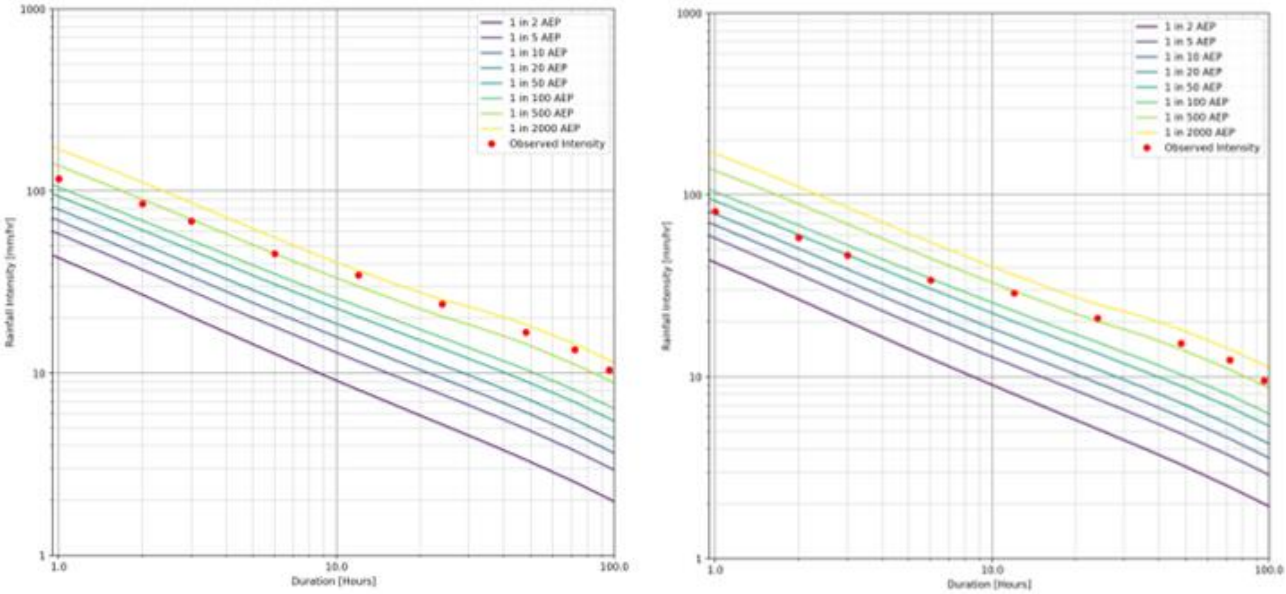
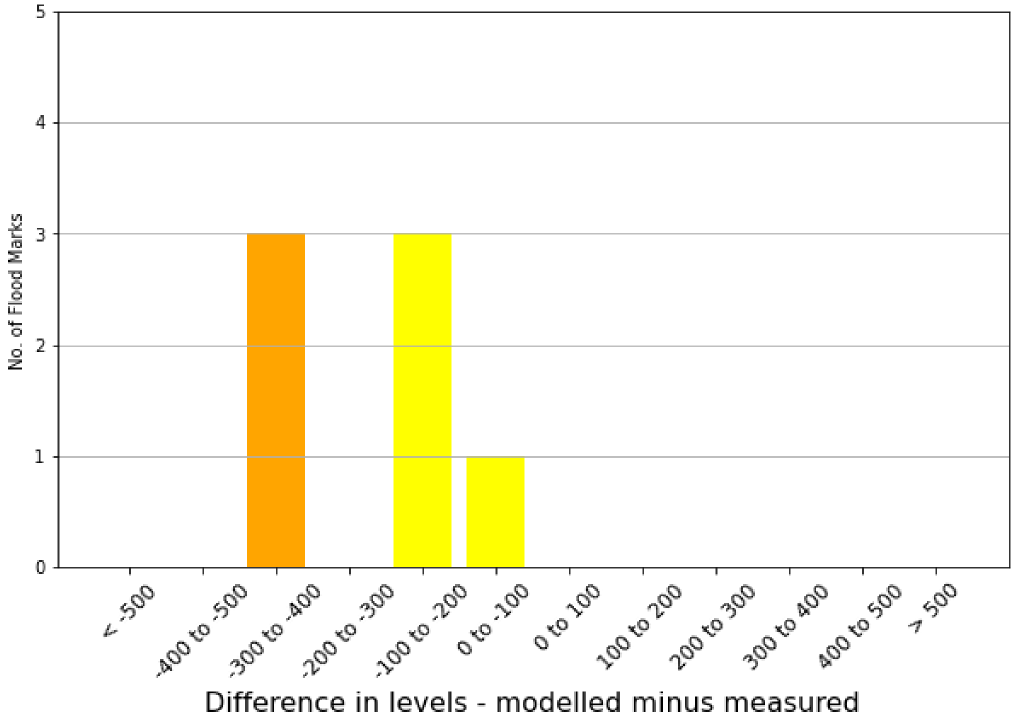


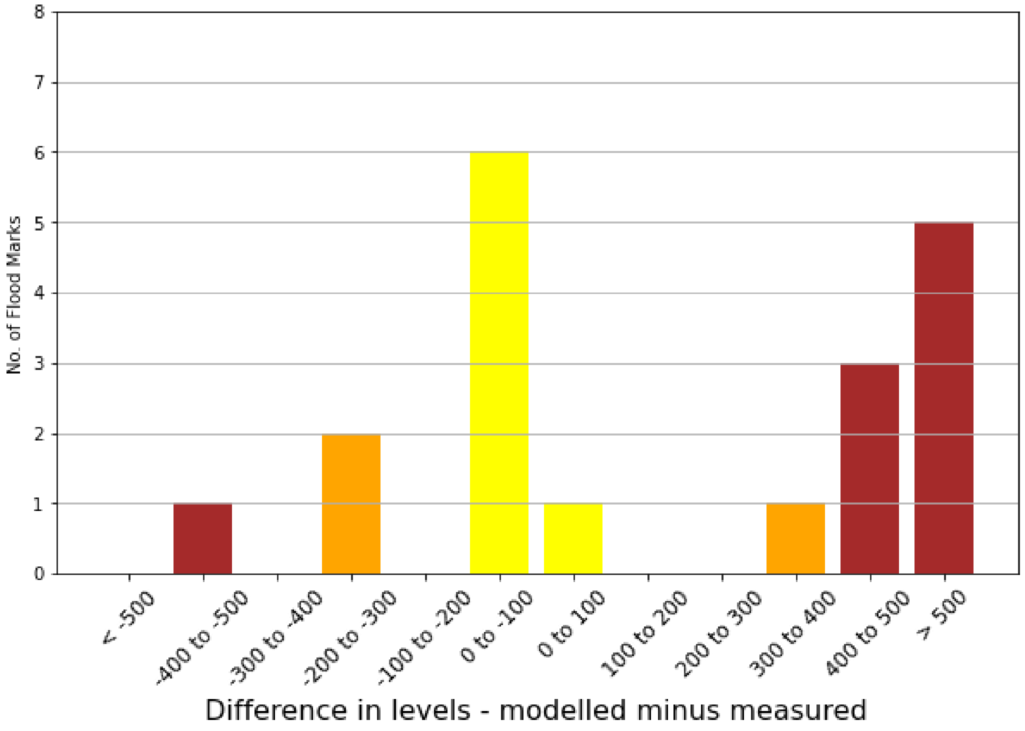
Figure 8-5 Estimated AEP of February 2022 event for Kippa-Ring Alert (540629) (left) and Woody Point Alert (540498) (right)

A-2 Debris Histograms

A-2-1 November 2014



A-2-2 February 2022



APPENDIX B
WBNM SUBCATCHMENT PROPERTIES

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCE018_00000	12.54	37.4	26.3	32
RCN042_00000	5.36	55.4	38.8	42.3
RCN034_02442	28.49	Revised subcatchment	31.6	34.7
RCN034_01936	12.953	Revised subcatchment	27	32.3
RCN019_00152	6.652	41.9	29.4	29.4
RCN019_00000	8.083	38.9	27.2	27.2
RCN034_01791	1.627	Revised subcatchment	7.5	7.5
RCN034_01449	5.183	Revised subcatchment	17.8	17.8
RCN034_01007	7.501	Revised subcatchment	0	1
RCN005_00381	9.646	Revised subcatchment	0.6	0.6
RCN005_00000	13.17	0.8	0.6	2.9
RCN034_00565	18.638	Revised subcatchment	0	0.2
RCN009_00361	21.192	44.4	31.1	31.1
RCN009_00000	46.072	22.3	15.6	18.7
RCN034_00000	11.001	18.4	0	0
RCE008_00808	23.575	50.4	38.5	46.4
RCE008_00619	7.334	81.3	77.9	87.6
RCE008_00454	5.565	44.7	36.2	46
RCE008_00350	11.248	49.2	36.3	45.8
RCE008_00000	4.102	50.8	35.5	44.4
RCS024_00000	1.555	28	19.6	25.7
RCS021_00148	13.204	50.9	35.6	48.2
RCS021_00000	1.847	41.5	29.1	31.6
RCS023_00212	1.78	42.8	29.9	54.6
RCS025_00000	2.48	51.2	35.8	59.6
RCS023_00000	3.847	62.4	44.3	48
RCS027_00089	1.407	27.8	19.5	35.6
RCS027_00000	1.774	49.4	34.5	35.4
RCN024_00119	0.641	55	38.5	48.4
RCN024_00000	9.574	43.8	30.6	40.5
RCE031_00000	4.853	44.3	31	36
RCN020_00158	4.754	44.7	31.3	31.4
RCN020_00067	0.542	53.3	37.3	41.1
RCN044_00000	2.404	50.9	35.7	35.7
RCN020_00000	1.458	30.4	21.3	29.7
RCN022_00086	2.22	45.4	31.8	31.8
RCN022_00000	0.79	17.8	12.5	15.9
RCE033_00000	0.352	88.3	61.8	67.3
RCE020_00097	5.334	56	39.2	56.2
RCE020_00000	0.429	82.6	57.8	62.3

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCE011_00639	7.69	43.1	30.2	38.3
RCE011_00339	7.126	47.3	33.1	46.5
RCE011_00255	9.771	49	34.3	46.5
RCE011_00099	4.915	54.2	37.9	47.3
RCE011_00000	5.777	23.4	16.4	17.9
RCE009_00689	12.648	54.5	38.2	38.2
RCE009_00576	8.691	48.2	33.8	40
RCE009_00365	3.308	55.8	39.1	49.5
RCE009_00317	1.609	52.1	36.5	47.6
RCE009_00253	0.523	59.6	41.7	44.4
RCE009_00000	7.752	40	28	42.2
RCE007_00340	12.027	51.3	35.9	35.9
RCE007_00157	6.019	53.7	37.6	46.3
RCE007_00000	6.412	44.1	30.9	35.2
RCE005_00112	22.932	53	37.1	43.4
RCE005_00000	8.587	38	26.7	29.9
RCE013_00000	4.118	31.6	31.4	37.3
RCE015_00000	9.086	32.2	25.9	25.9
RCE016_00000	5.223	44.8	44.8	54.6
RCE003_00939	4.897	16.3	16.3	16.3
RCE003_00800	3.127	59.6	54.6	62.7
RCE003_00673	1.734	25.1	22.8	24.1
RCE003_00537	9.825	45.3	31.8	37.1
RCE003_00389	18.487	51.7	36.2	36.2
RCE003_00071	20.593	50.2	35.1	42.1
RCE003_00000	6.829	37.2	26.1	33.3
RCE001_01989	22.133	45	31.5	31.5
RCE001_01609	35.311	41.7	29.2	29.2
RCE001_01494	3.645	37.2	26.8	26.8
RCE029_00000	24.513	40	28.5	29.3
RCE001_01440	0.662	50.4	49.7	49.7
RCE001_01082	16.137	48.1	46.6	46.6
RCE001_00943	6.695	42.8	36.5	45.7
RCE001_00802	5.377	32.9	26.2	38.6
RCE001_00728	3.942	59.9	48.2	57
RCE001_00566	2.1	39.2	39.2	59.5
RCE019_00000	4.914	50.8	50.8	50.8
RCE021_00000	3.375	22.9	22.9	22.9
RCE023_00000	8.182	54.7	52.2	66.8
RCE017_00897	8.316	73.9	73.9	87.4

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCE017_00233	3.244	82	82	83.6
RCE017_00000	6.593	56.1	56.1	84
RCE001_00428	3.549	58.6	58.6	80.4
RCE001_00255	9.992	53.6	53.6	66.4
RCE001_00197	7.264	86.2	86.2	91.7
RCE001_00000	18.137	63.7	63.8	69.6
RCE002_00000	9.906	56.5	40.2	53.7
RCE006_00000	1.684	62.8	44	48.6
RCE004_00410	4.268	53.2	37.2	47
RCE004_00173	8.522	48.5	34	40.3
RCE004_00063	0.386	62.9	44	50.9
RCE025_00123	7.043	51	35.7	59
RCE027_00000	12.419	47.4	33.2	58
RCE025_00000	7.918	48.3	33.8	57.7
RCE004_00000	4.23	43.1	30.2	31.3
RCE014_00000	11.391	49.5	37.8	52.6
RCE010_00699	8.809	44.4	31	38.8
RCE010_00476	15.407	47.9	35.2	41.9
RCE010_00265	11.139	41.3	30.4	40.5
RCE010_00000	6.151	39.1	28.6	36.8
RCE012_00000	18.838	42.3	29.7	35.1
RCS019_00000	4.999	47.2	33	39.3
RCS022_00323	13.281	37.4	26.2	28.9
RCS022_00147	2.68	39.5	27.6	29.9
RCS022_00000	1.155	28.1	19.7	19.7
RCS009_00862	22.687	44	30.8	33.2
RCS009_00553	7.882	42.4	29.7	30.7
RCS009_00409	1.73	51.7	36.2	43.3
RCS009_00117	2.574	42.9	30	35
RCS011_00712	11.362	52.9	37	44.6
RCS011_00600	1.251	54.7	38.3	43.7
RCS017_00000	2.715	51.9	36.3	40.3
RCS011_00440	4.466	53.4	37.4	44.2
RCS011_00350	3.588	50.3	35.2	40
RCS011_00000	3.552	34.3	24	28.7
RCS009_00065	0.962	43.5	30.4	40.9
RCS009_00000	4.055	15.7	11	13.8
RCS008_00000	10.201	30.3	21.2	24.2
RCS006_00214	22.538	42.3	29.6	31.4
RCS006_00000	3.188	37.4	26.2	26.5

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCS004_00653	18.845	42.3	29.6	30.2
RCS004_00477	3.194	44.6	31.2	31.9
RCS004_00409	3.149	40.5	28.3	28.7
RCS004_00223	3.233	35.4	24.7	30.6
RCS004_00000	4.192	31.1	21.7	26
RCS007_00000	9.855	42.5	29.8	29.8
RCS002_00000	4.693	40.5	28.3	29.3
RCS003_00344	10.318	40.6	28.4	28.4
RCS003_00251	2.122	36.5	25.6	25.6
RCS005_00120	9.467	24.3	17	20
RCS005_00000	2.148	38.2	26.7	26.7
RCS003_00000	4.573	28.6	20	20
RCS001_02739	9.714	28.7	20.1	22.2
RCS001_02523	11.486	35.7	25	25
RCS001_02198	19.661	37.1	26	26
RCS001_01737	37.977	38	26.6	26.6
RCS001_01556	12.987	48.1	33.7	33.8
RCS001_01199	24.608	35.4	24.8	25.4
RCS001_00906	20.693	38.1	27	27
RCS001_00687	16.428	40.9	28.7	28.7
RCS001_00602	1.247	16.1	11.2	11.2
RCS001_00460	11.397	40.5	28.4	28.4
RCS001_00257	5.138	29.5	20.6	20.6
RCS001_00082	21.691	50.2	35.2	40.2
RCS001_00000	5.993	24	18	18
RCS031_00000	5.815	39.4	27.5	27.5
RCS010_00871	8.305	44.2	31	31
RCS010_00772	0.375	49.2	34.4	36.4
RCS033_00000	3.168	43	30.1	30.1
RCS010_00661	0.453	57.3	40.1	40.1
RCS029_00000	5.331	42.6	29.8	29.8
RCS010_00430	2.209	40.3	28.2	28.2
RCS013_00000	2.456	44.3	31	31
RCS020_00000	2.092	42.3	29.6	29.6
RCS012_00315	1.832	33.8	23.6	23.6
RCS012_00208	3.686	40	28	28
RCS012_00113	0.486	44.7	31.3	33.8
RCS015_00000	1.616	41.6	29.2	29.2
RCS012_00000	0.752	47.7	33.4	34.4
RCS010_00195	8.277	47	32.9	43.7

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCS010_00000	6.609	37.4	26.2	26.9
RCS016_00000	1.721	39.6	27.7	36.6
RCS014_00464	3.226	42.6	29.8	38.7
RCS014_00235	2.125	39.7	27.8	38.9
RCS018_00000	3.15	41.4	29	47.9
RCS014_00083	2	48.6	34	49.4
RCS014_00000	0.642	17.4	12.3	13.7
RCN018_00438	5.536	48.6	34	42.8
RCN018_00266	4.625	50.8	35.5	42.5
RCN018_00065	3.097	46.8	32.8	40.1
RCN018_00000	2.021	64.5	45.7	63
RCN016_00612	6.869	39.5	27.7	27.8
RCN016_00350	8.371	39.6	27.7	32.9
RCN016_00223	4.878	41.3	28.9	34.7
RCN016_00098	7.08	50.3	35.2	41.6
RCN016_00000	3.541	43.6	30.6	43.1
RCN014_00249	12.721	39.4	27.6	31.6
RCN014_00000	11.352	42.2	29.6	36
RCN007_01711	12.803	21.5	15.1	45.3
RCN023_00000	8.634	5.3	3.8	39
RCN007_01621	5.272	0.6	0.4	44.9
RCN007_01503	1.255	0	0	46.7
RCN021_00000	13.302	1.3	0.9	43.4
RCN007_01174	10.001	5.8	5.8	39.7
RCN007_00000	50.945	39.4	37	37
RCN025_00000	16.352	40.3	28.2	40.2
RCN003_00955	10.421	35.1	24.5	24.5
RCN003_00000	27.679	58.2	51.2	51.2
RCN008_01048	6.232	41.3	28.9	28.9
RCN008_00854	6.774	41	28.7	28.7
RCN008_00704	2.555	42.9	30.3	30.3
RCN008_00305	10.305	56.9	47.9	47.9
RCN028_00000	4.547	41.4	29	29
RCN010_00945	4.724	36.8	25.8	25.8
RCN026_00000	15.499	45.8	32.1	32.1
RCN010_00850	1.153	19.2	13.4	14.5
RCN011_00000	1.414	35	24.5	24.5
RCN010_00749	0.866	29.2	20.4	20.4
RCN013_00000	1.63	40.6	28.4	30.1
RCN030_00000	4.326	46.6	32.6	32.6

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCN010_00616	1.179	38.7	27.1	27.1
RCN032_00000	4.935	44.8	31.4	32.8
RCN010_00000	22.627	59.1	50.8	50.8
RCN008_00000	3.692	64.2	56.5	56.5
RCN004_00404	13.653	40.5	29.6	31.9
RCN004_00220	7.501	30.9	21.6	24.1
RCN004_00000	5.863	41	28.7	30.6
RCN015_00091	2.683	33.3	23.3	27
RCN015_00000	1.18	43.7	30.6	35.4
RCN002_02236	8.117	58.4	47.4	62
RCN002_01732	18.79	40.1	28.2	31.5
RCN002_01467	7.934	43.5	30.5	33.4
RCN002_01356	1.249	33.9	23.8	26.7
RCN002_01194	20.295	42.5	30.1	34.1
RCN002_00903	7.594	36.5	26	28
RCN002_00777	1.372	45.5	33.7	33.7
RCN002_00623	5.054	58.8	44.6	44.6
RCN006_00692	18.181	37.8	26.4	26.4
RCN006_00592	4.32	41.2	28.9	28.9
RCN006_00175	12.293	38.1	26.7	26.9
RCN006_00000	2.574	59.2	49.2	49.2
RCN002_00306	10.257	56.6	47.4	47.4
RCN002_00000	11.918	59.2	50.4	50.4
RCN027_00000	7.849	5.6	4.1	4.1
RCN029_00629	6.707	29.4	20.6	20.6
RCN029_00329	11.134	28	19.6	19.6
RCN031_00000	4.95	26.6	18.8	18.8
RCN036_00000	16.314	49	34.3	36.5
RCN017_00000	50.191	60.1	53	60.9
RCN038_00000	18.664	39.5	27.6	30.3
RCN001_03378	13.042	39.2	27.5	28.4
RCN001_03083	18.382	38.5	26.9	38.4
RCN001_02867	17.939	46.4	33.8	48.6
RCN001_02698	8.632	79	76.5	81.9
RCN001_02363	7.867	60	55.6	63
RCN001_02281	7.531	61.8	53.3	56.1
RCN001_01845	31.871	43.5	30.9	36.7
RCN001_01427	25.855	34	25.5	25.5
RCN001_01018	16.192	40	31.7	31.7
RCN001_00908	4.948	57.1	46.5	46.5

WBNM Subcatchment ID	Area (ha)	Stage 2 hydrography Impervious (%)	Updated Current EIA (%)	Ultimate EIA (%)
RCN001_00617	8.702	67.6	60.1	60.1
RCN001_00469	15.286	64.8	56.6	56.6
RCN012_01238	23.773	20.6	14.5	16
RCN012_00853	13.103	44.7	31.3	35.2
RCN012_00693	3.817	45.8	32.1	32.1
RCN012_00000	9.709	63.7	54.8	54.8
RCN001_00000	24.56	53.2	43.7	43.7
RCN040_00000	12.608	42.7	29.9	29.9
DUMMY	0	100	100	100

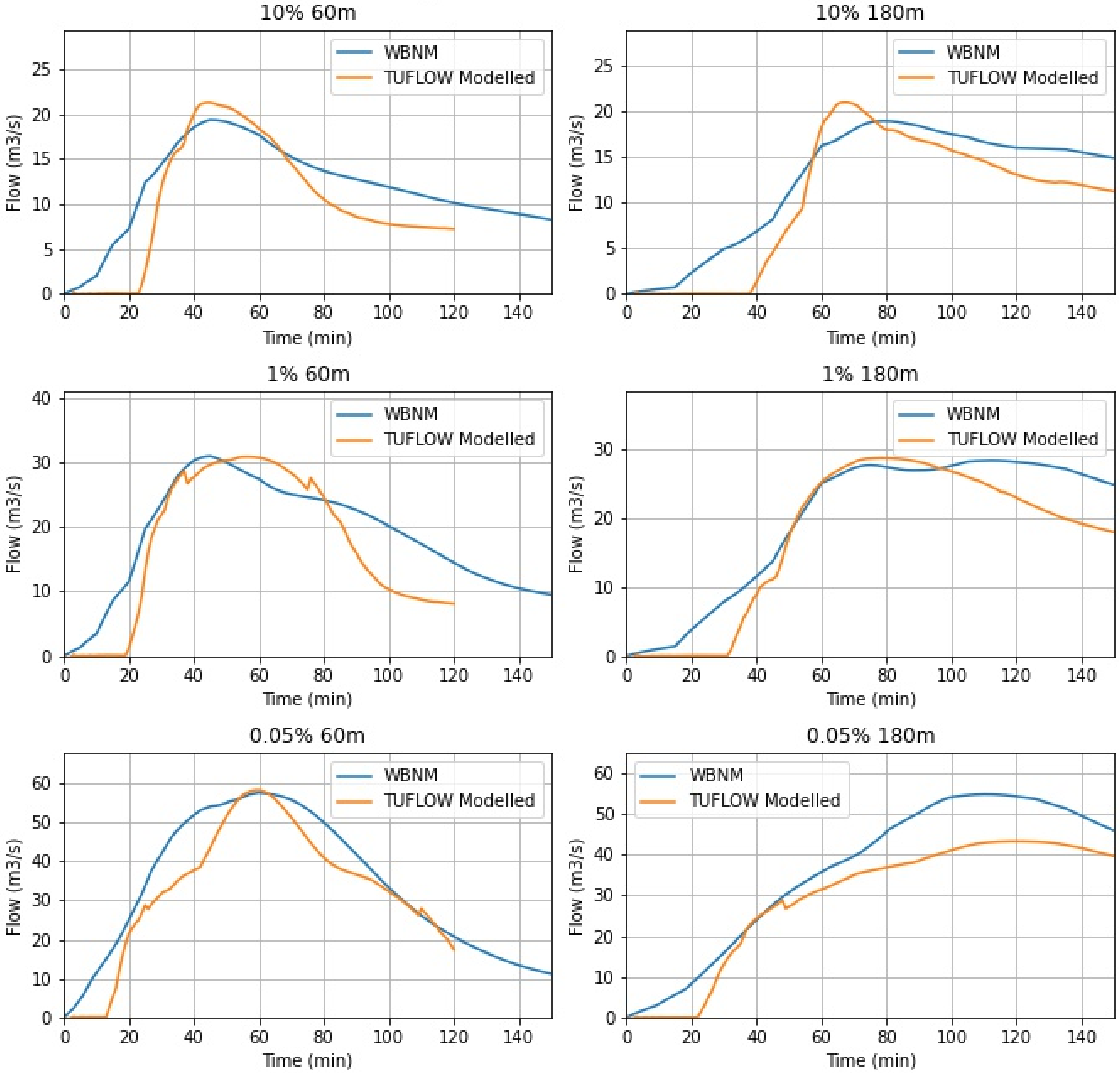
APPENDIX C
HEH PLOTS AND SUMMARY TABLES

POI	Artificial Storage Required?	Storage description	HEH criteria met?	Justification if criteria not met?
RCS027_00089	✗	-	✗	Receives overflow in events greater than 10% AEP event. Good match on rising limb before breakout flow arrives.
RCS010_00195	✓	Upstream urban catchments have significant storage with significant ponding of flows along Thomas Street and Cornelius Street.	✓	-
RCS009_00065	✓	Significant storage in Woody Point north park upstream of Hornibrook Esplanade.	✓	-
RCS001_02198	✓	Storage upstream of Maine Road and MacDonnell park.	✓	-
RCS001_01556	✗	-	✓	-
RCS001_00906	✗	-	✓	-
RCS001_00000	✗	-	✗	POI is within canal which affects hydrograph shape depending on tailwater condition. Unrealistic to represent complex hydraulics in hydrologic model.
RCN016_00223	✗	-	✓	-
RCN007_00000	✓	Newport canal with lock and weir outlet configuration.	✗	3/6 events meet criteria. Complex location with Newport canal and weir flow.
RCN002_00777	✗	-	✗	4/6 events meet criteria. All events have NSE over 0.9.

POI	Artificial Storage Required?	Storage description	HEH criteria met?	Justification if criteria not met
RCN001_01427	✗	-	✓	-
RCN001_00000	✗	-	✗	POI is within canal which affects hydrograph shape depending on tailwater condition. Unrealistic to represent complex hydraulics in hydrologic model.
RCE025_00000	✓	Marine Parade does not overtop and therefore storage upstream with trunk drains at capacity.	✗	Rising limb shows good match. Receding limb has poor shape. Several storage curves attempted without any success.
RCE010_00265	✗	-	✓	-
RCE010_00000	✗	-	✗	All events except for 0.05% AEP event showing very good match. 0.05% showing good match of shape and 15% peak difference.
RCE009_00000	✗	-	✓	-
RCE008_00454	✗	-	✓	-
RCE008_00000	✗	-	✗	All events except for 0.05% AEP event showing very good match.
RCE004_00173	✗	-	✗	Receives overflow in events greater than 10% AEP event. Good match on rising limb before breakout flow arrives.
RCE003_00071	✗	-	✓	-

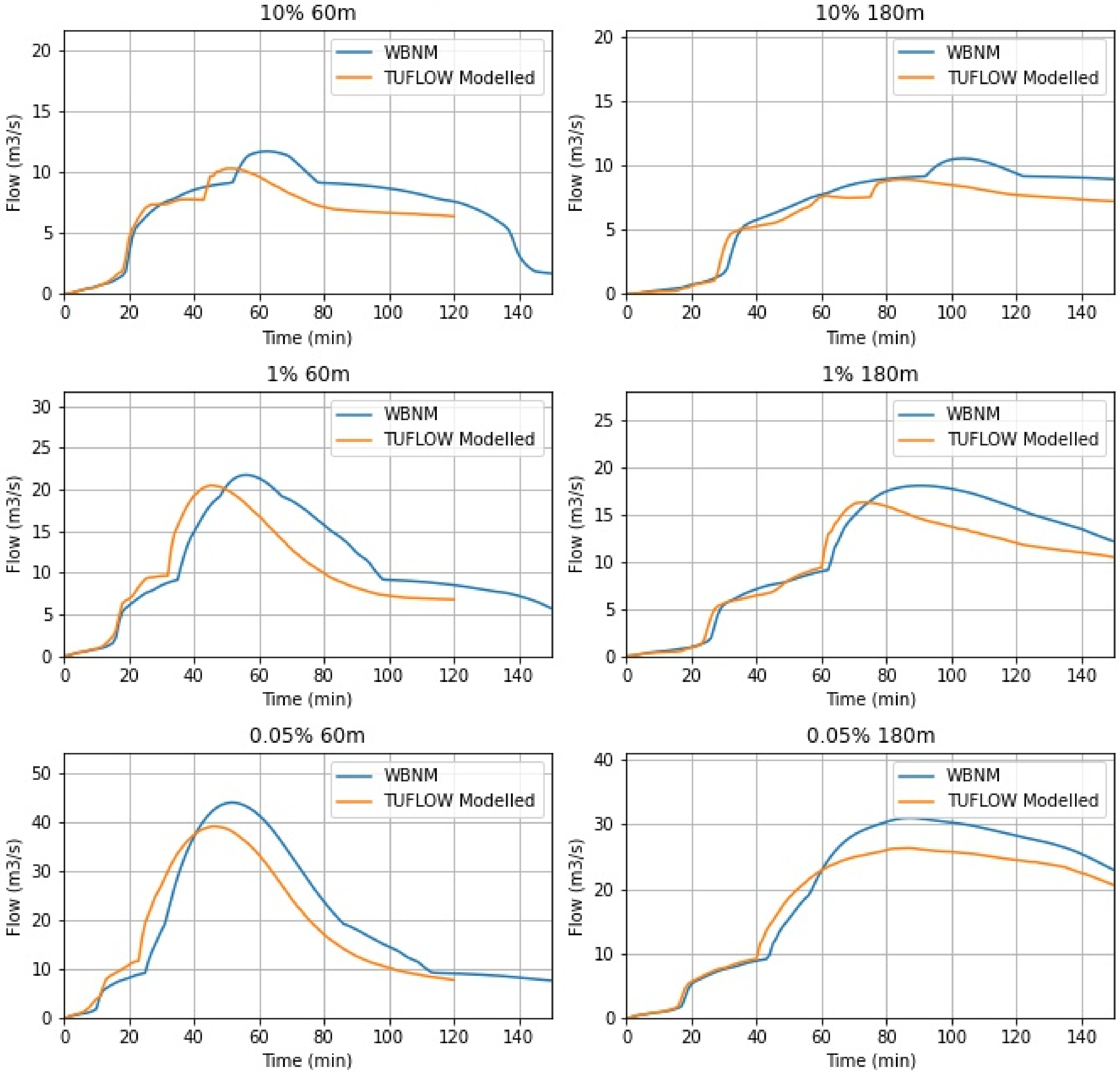
POI	Artificial Storage Required?	Storage description	HEH criteria met?	Justification if criteria not met
RCE001_01440	✗	-	✓	-
RCE001_01082	✓	Significant storage in Redcliffe Harness Racing and Sporting club.	✗	4/6 events meet criteria
RCE001_00000	✗	-	✗	4/6 events meet criteria. Complex location with culverts underneath Redcliffe Parade and storages upstream.

RCE001_00000 HEH Modelling



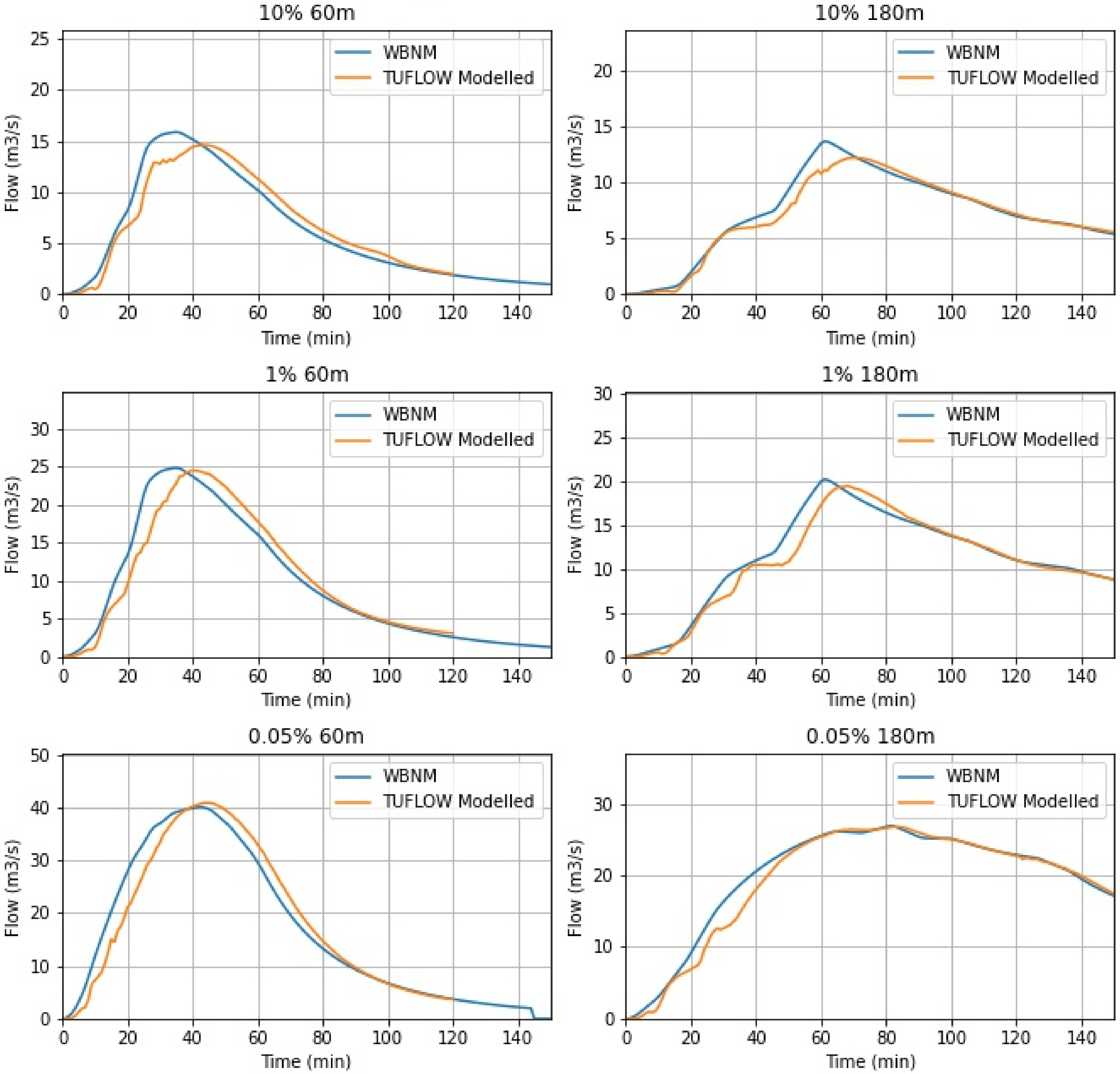
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	9.79%	1.0	0.75
10% 180m	10.77%	12.0	0.88
1% 60m	0.33%	12.0	0.77
1% 180m	1.37%	34.0	0.94
0.05% 60m	1.09%	1.0	0.84
0.05% 180m	21.0%	8.0	0.79

RCE001_01082 HEH Modelling



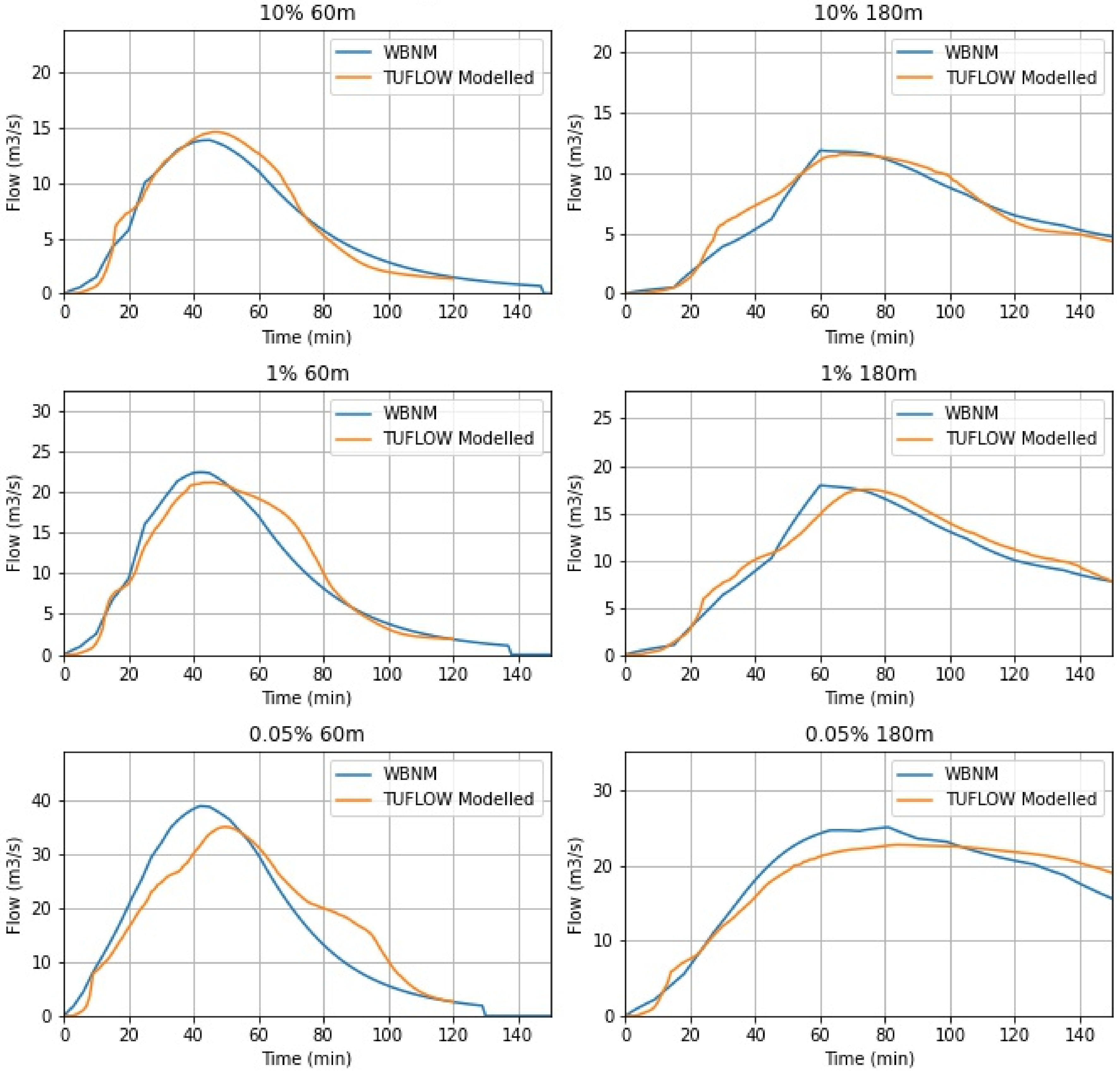
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	11.94%	11.0	0.72
10% 180m	15.4%	19.0	0.89
1% 60m	5.76%	11.0	0.66
1% 180m	9.79%	17.0	0.85
0.05% 60m	11.08%	6.0	0.8
0.05% 180m	15.03%	1.0	0.9

RCE001_01440 HEH Modelling



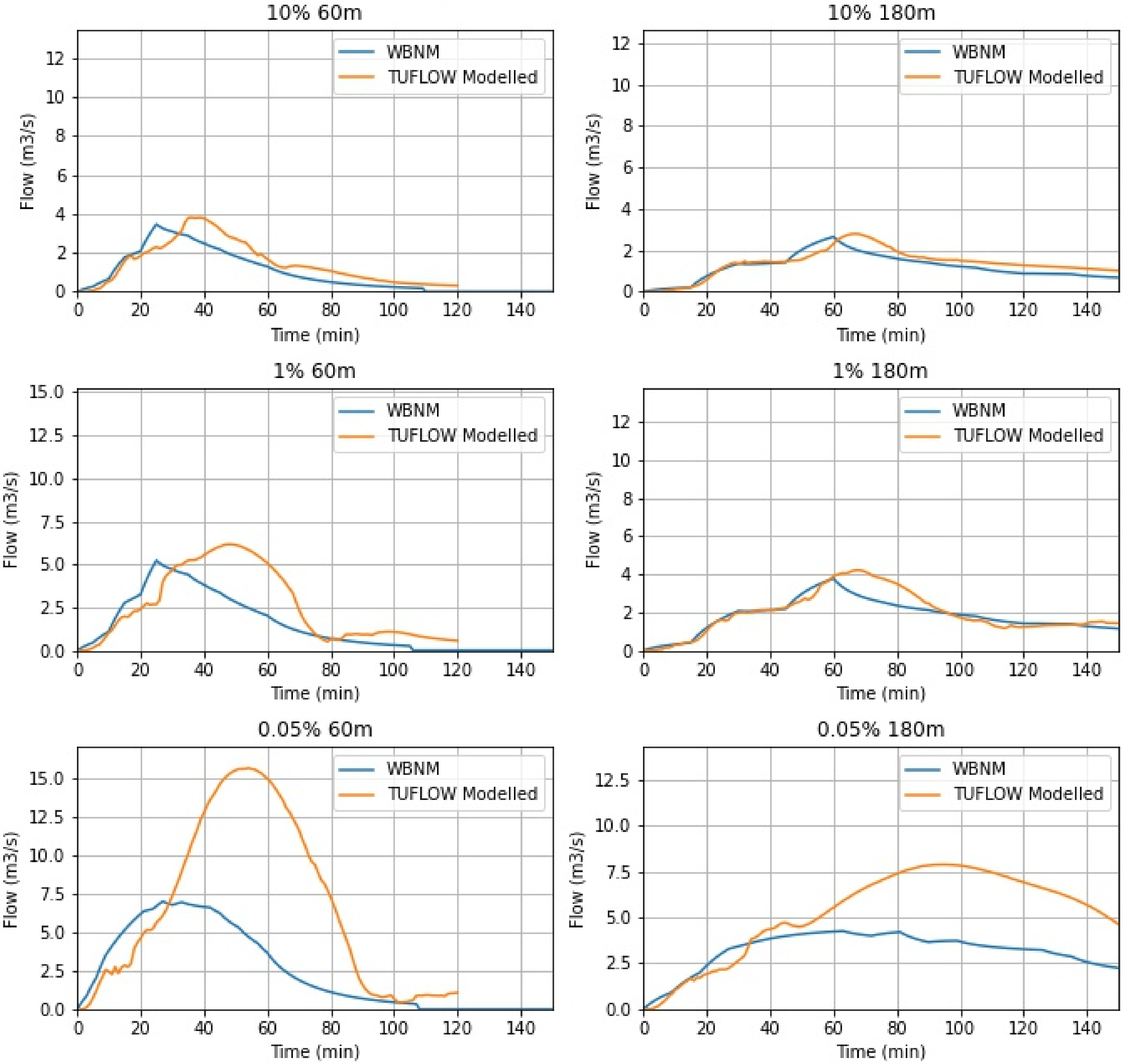
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	8.03%	8.0	0.92
10% 180m	10.74%	9.0	0.95
1% 60m	1.28%	5.0	0.92
1% 180m	3.59%	7.0	0.95
0.05% 60m	1.94%	2.0	0.95
0.05% 180m	0.46%	2.0	0.97

RCE003_00071 HEH Modelling



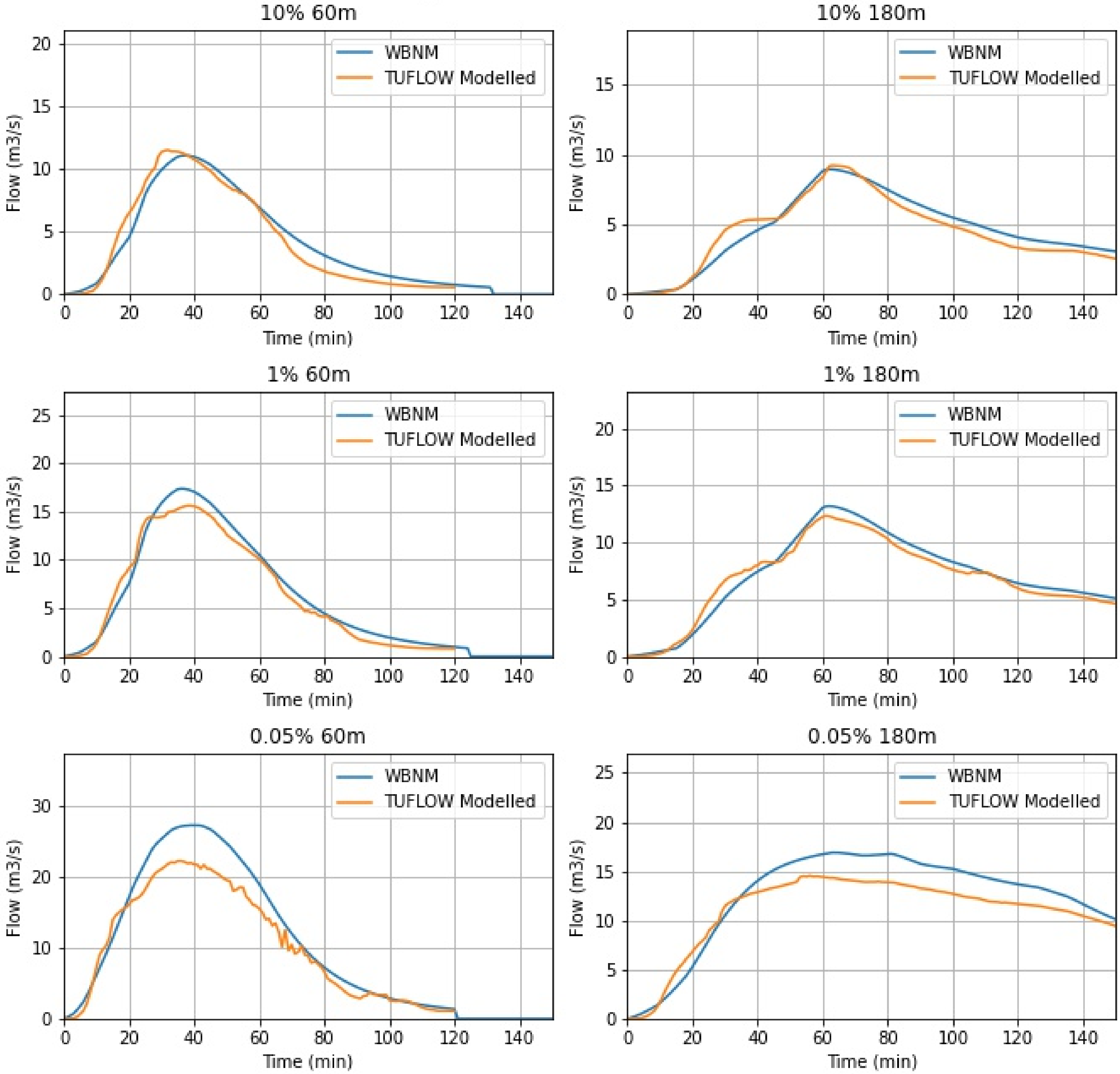
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	5.32%	2.0	0.97
10% 180m	2.76%	7.0	0.95
1% 60m	5.56%	4.0	0.94
1% 180m	2.42%	14.0	0.96
0.05% 60m	9.96%	8.0	0.77
0.05% 180m	9.28%	3.0	0.94

RCE004_00173 HEH Modelling



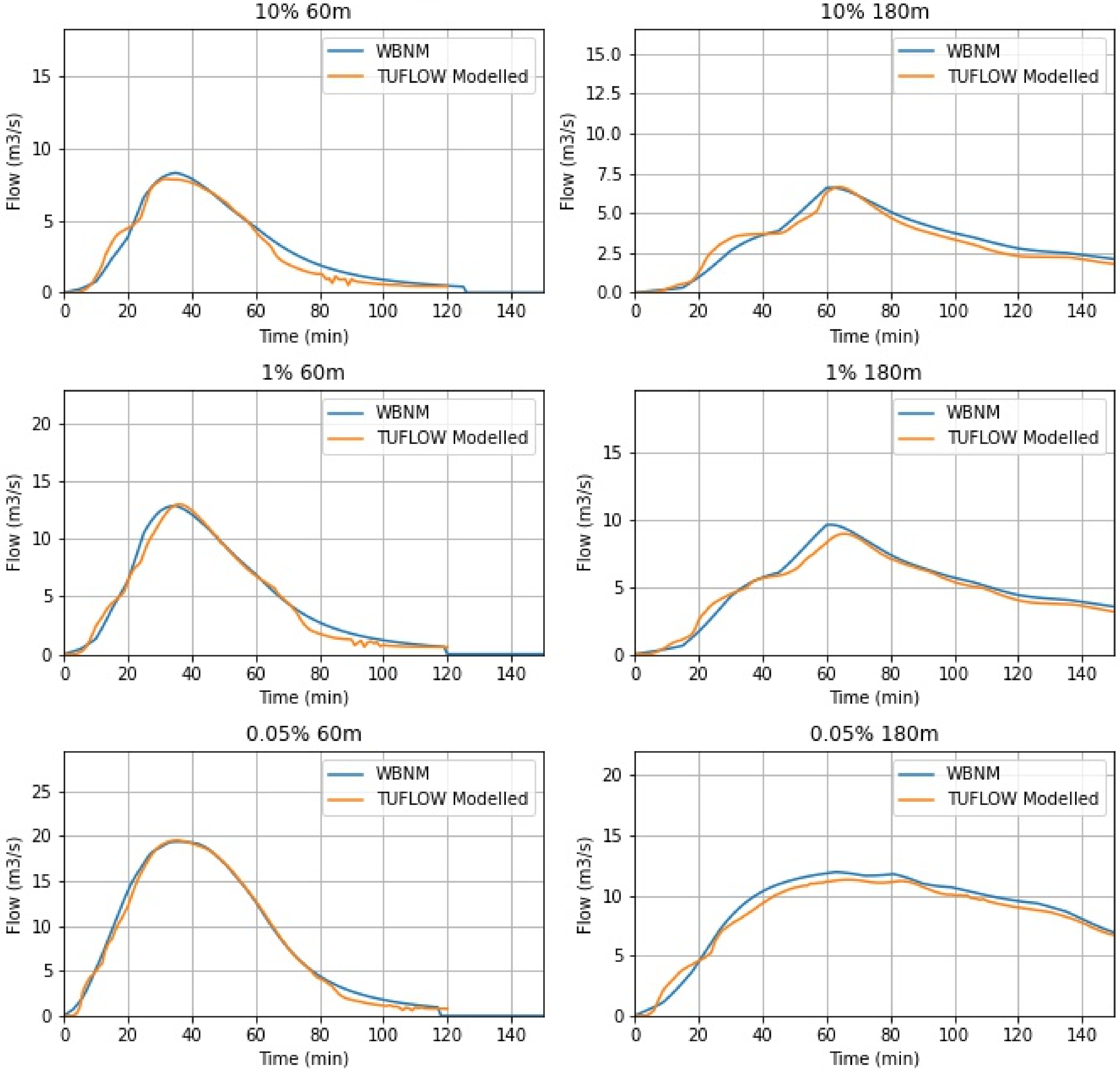
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	10.07%	11.0	0.72
10% 180m	5.14%	7.0	0.79
1% 60m	17.86%	23.0	0.49
1% 180m	11.6%	8.0	0.8
0.05% 60m	123.71%	27.0	0.22
0.05% 180m	85.13%	32.0	0.32

RCE008_00000 HEH Modelling



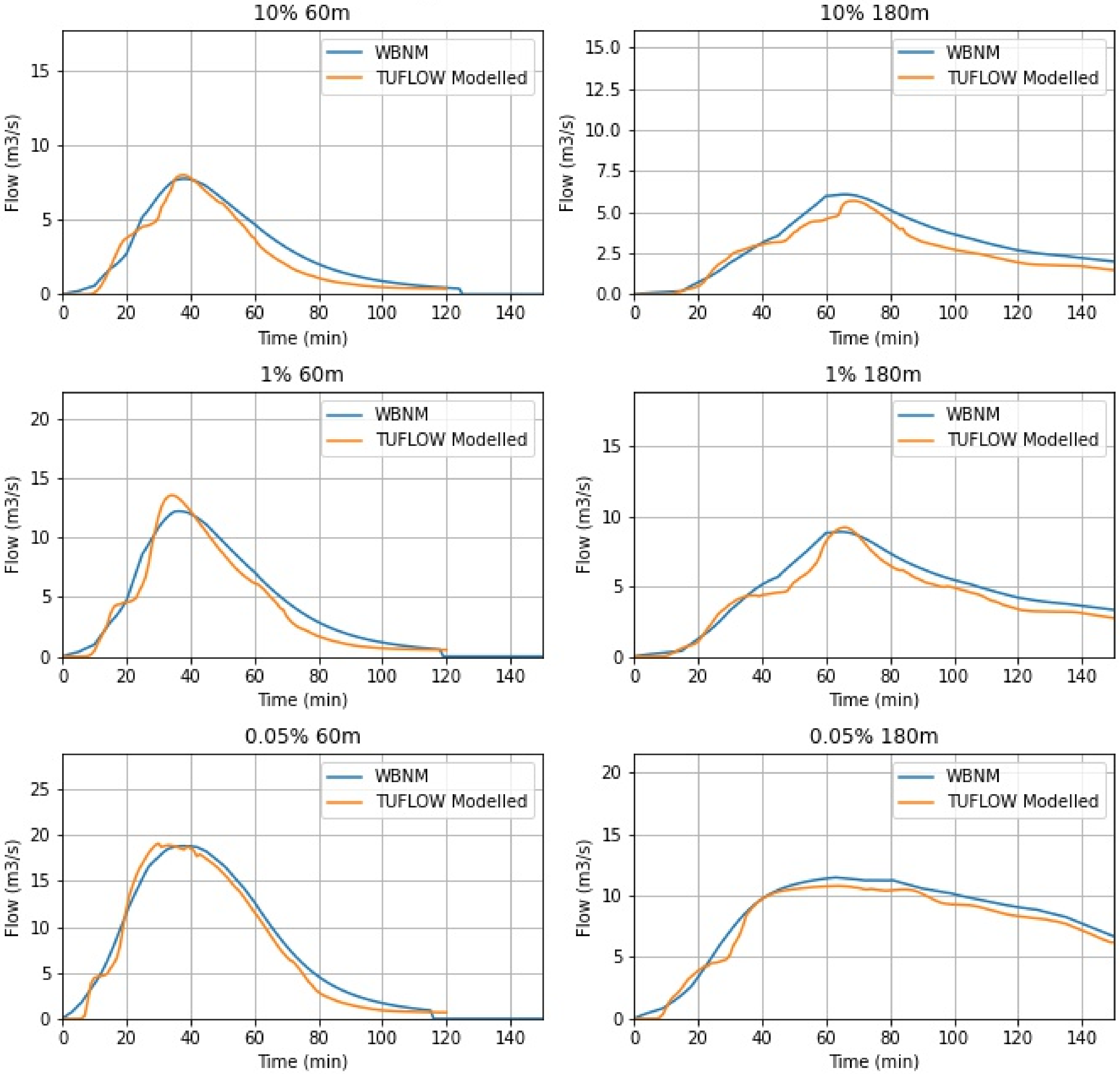
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	3.91%	5.0	0.96
10% 180m	3.08%	1.0	0.94
1% 60m	10.14%	2.0	0.97
1% 180m	6.41%	1.0	0.96
0.05% 60m	18.48%	4.0	0.87
0.05% 180m	13.93%	8.0	0.8

RCE008_00454 HEH Modelling



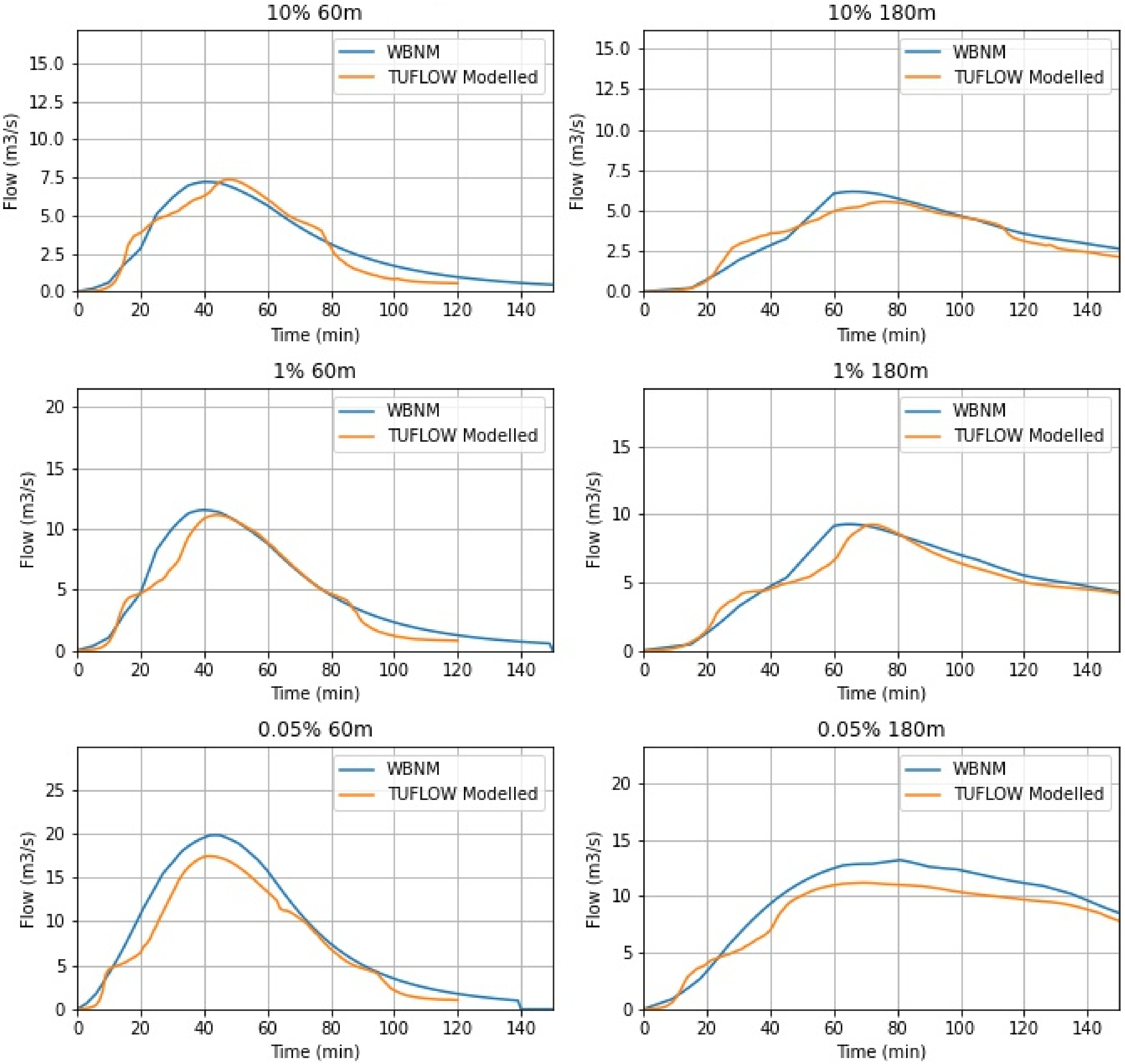
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	5.17%	4.0	0.97
10% 180m	0.71%	3.0	0.94
1% 60m	0.96%	1.0	0.98
1% 180m	6.96%	5.0	0.96
0.05% 60m	0.76%	1.0	0.99
0.05% 180m	5.33%	4.0	0.96

RCE009_00000 HEH Modelling



	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	3.09%	0.0	0.93
10% 180m	6.51%	3.0	0.84
1% 60m	10.98%	2.0	0.95
1% 180m	3.65%	1.0	0.92
0.05% 60m	1.39%	8.0	0.98
0.05% 180m	5.99%	1.0	0.96

RCE010_00000 HEH Modelling



10% 60m

10% 180m

1% 60m

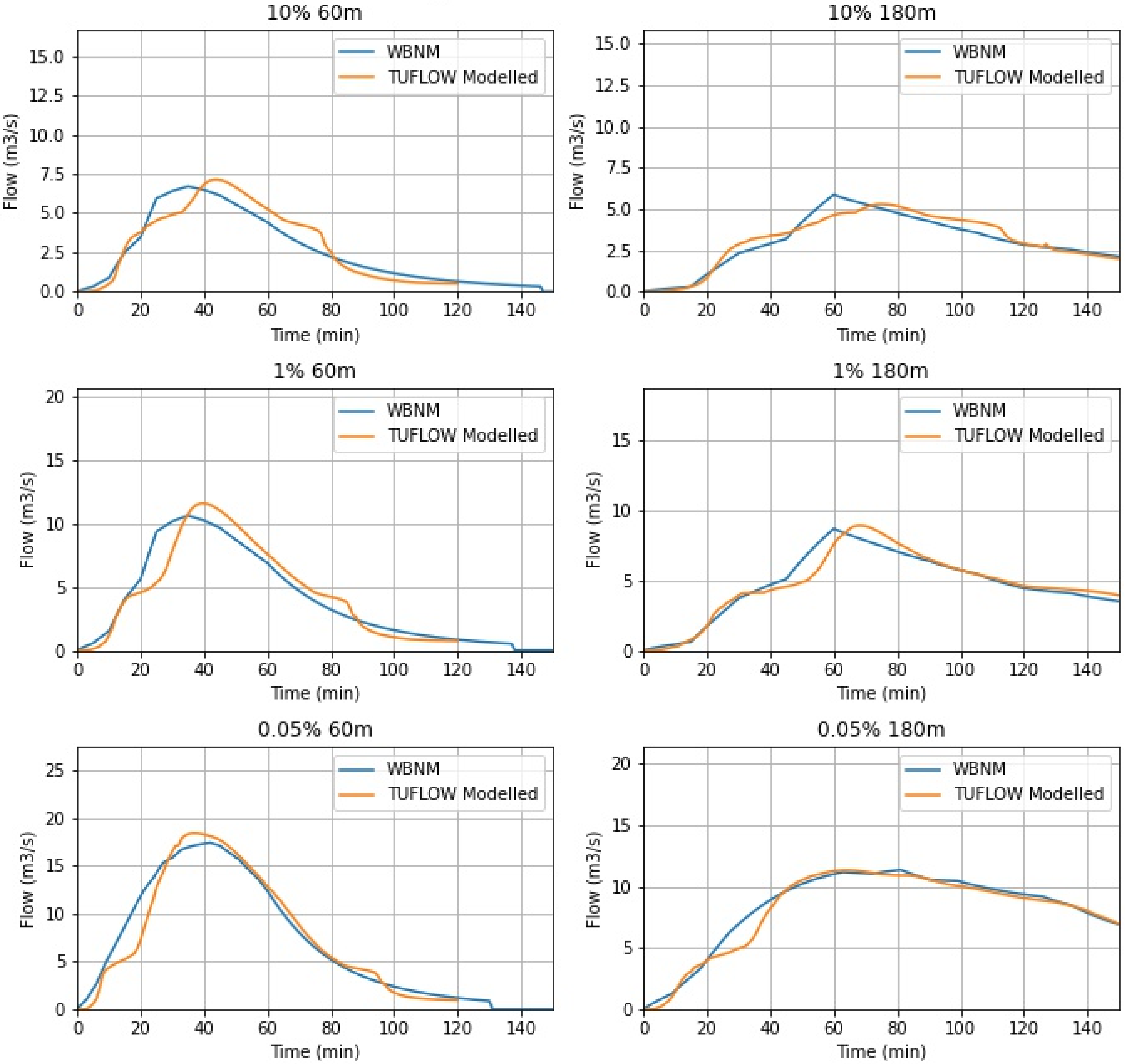
1% 180m

0.05% 60m

0.05% 180m

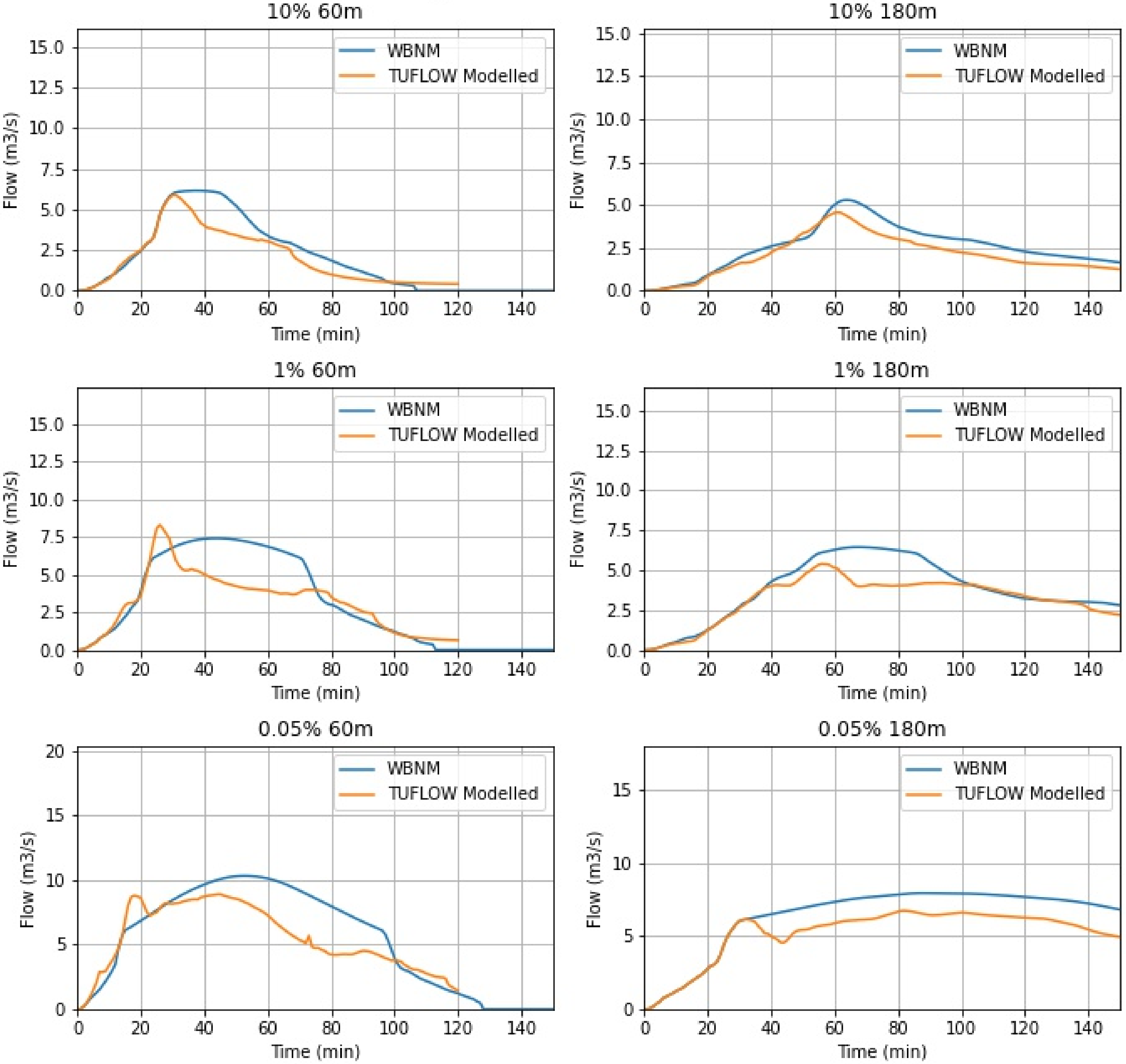
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	1.98%	8.0	0.93
10% 180m	10.1%	10.0	0.92
1% 60m	3.65%	4.0	0.91
1% 180m	0.45%	7.0	0.91
0.05% 60m	12.14%	1.0	0.88
0.05% 180m	15.23%	12.0	0.84

RCE010_00265 HEH Modelling



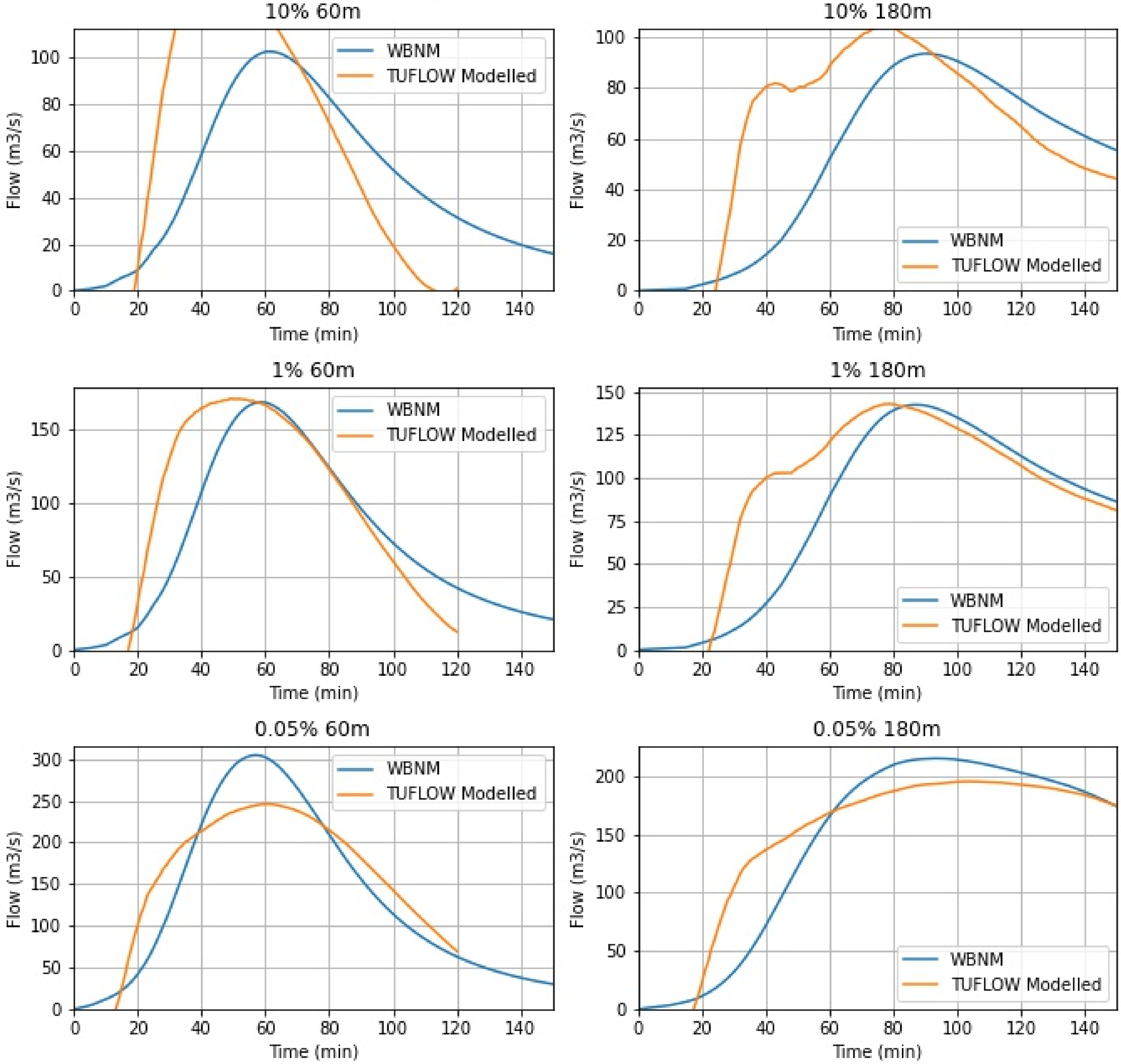
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	6.39%	9.0	0.89
10% 180m	9.76%	15.0	0.91
1% 60m	8.98%	5.0	0.89
1% 180m	2.63%	8.0	0.93
0.05% 60m	5.77%	5.0	0.95
0.05% 180m	0.25%	17.0	0.96

RCE025_00000 HEH Modelling



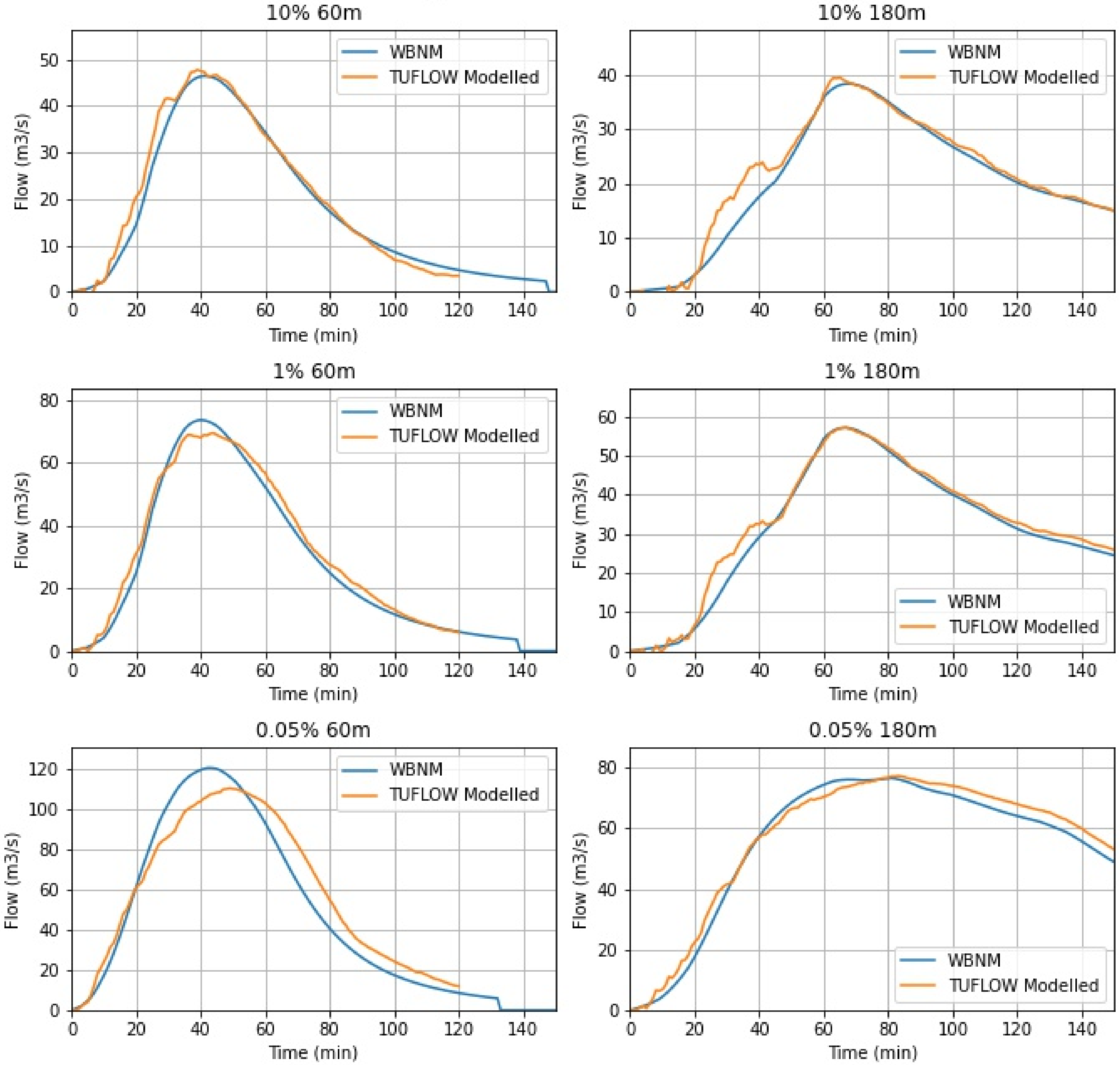
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	4.57%	6.0	0.73
10% 180m	13.77%	3.0	0.79
1% 60m	11.95%	18.0	0.38
1% 180m	16.36%	11.0	0.56
0.05% 60m	13.78%	8.0	0.44
0.05% 180m	15.18%	6.0	0.7

RCN001_00000 HEH Modelling



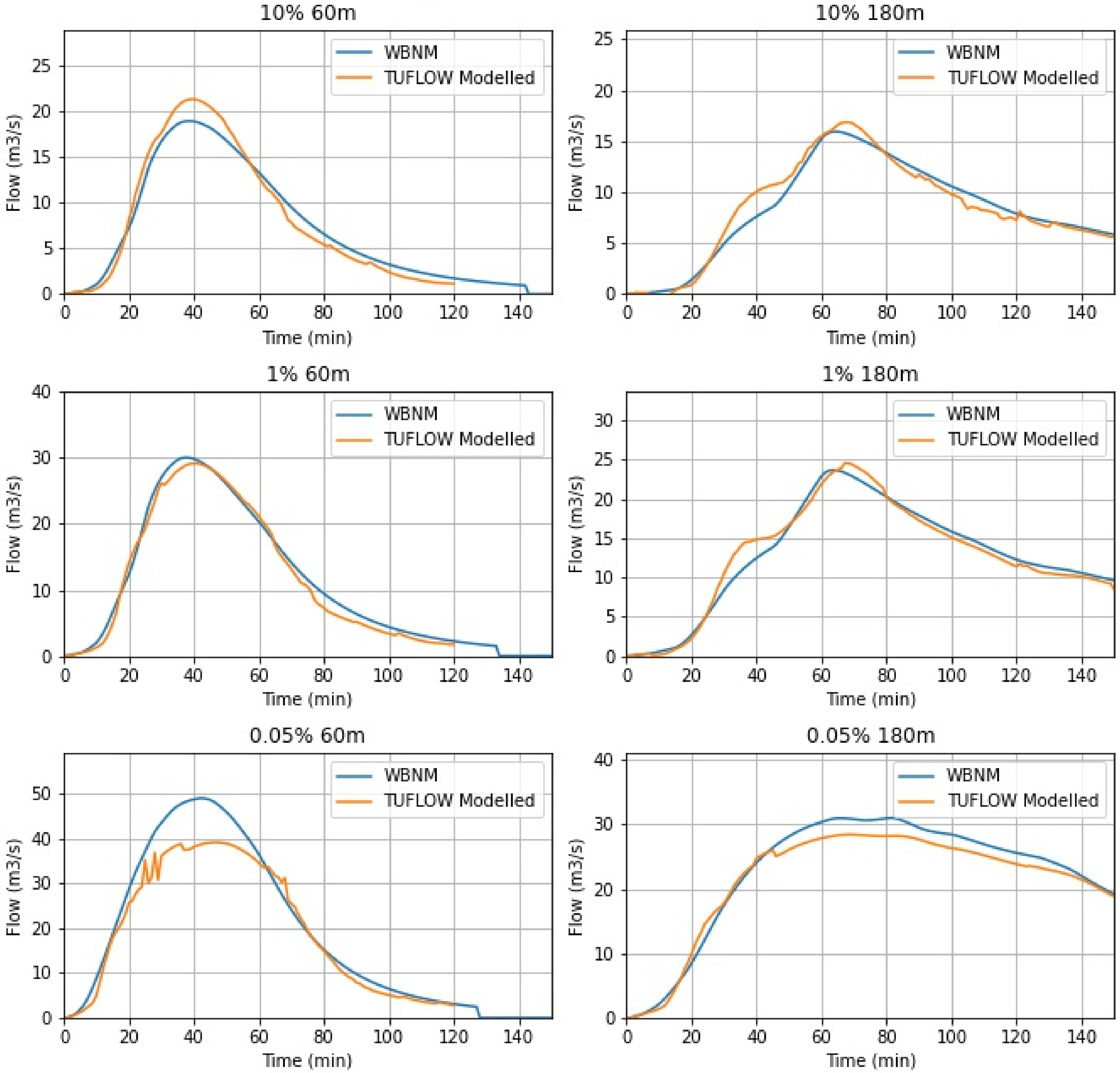
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	29.24%	18.0	0.54
10% 180m	11.73%	12.0	0.55
1% 60m	1.4%	10.0	0.77
1% 180m	0.33%	8.0	0.7
0.05% 60m	19.3%	3.0	0.8
0.05% 180m	9.18%	11.0	0.8

RCN001_01427 HEH Modelling



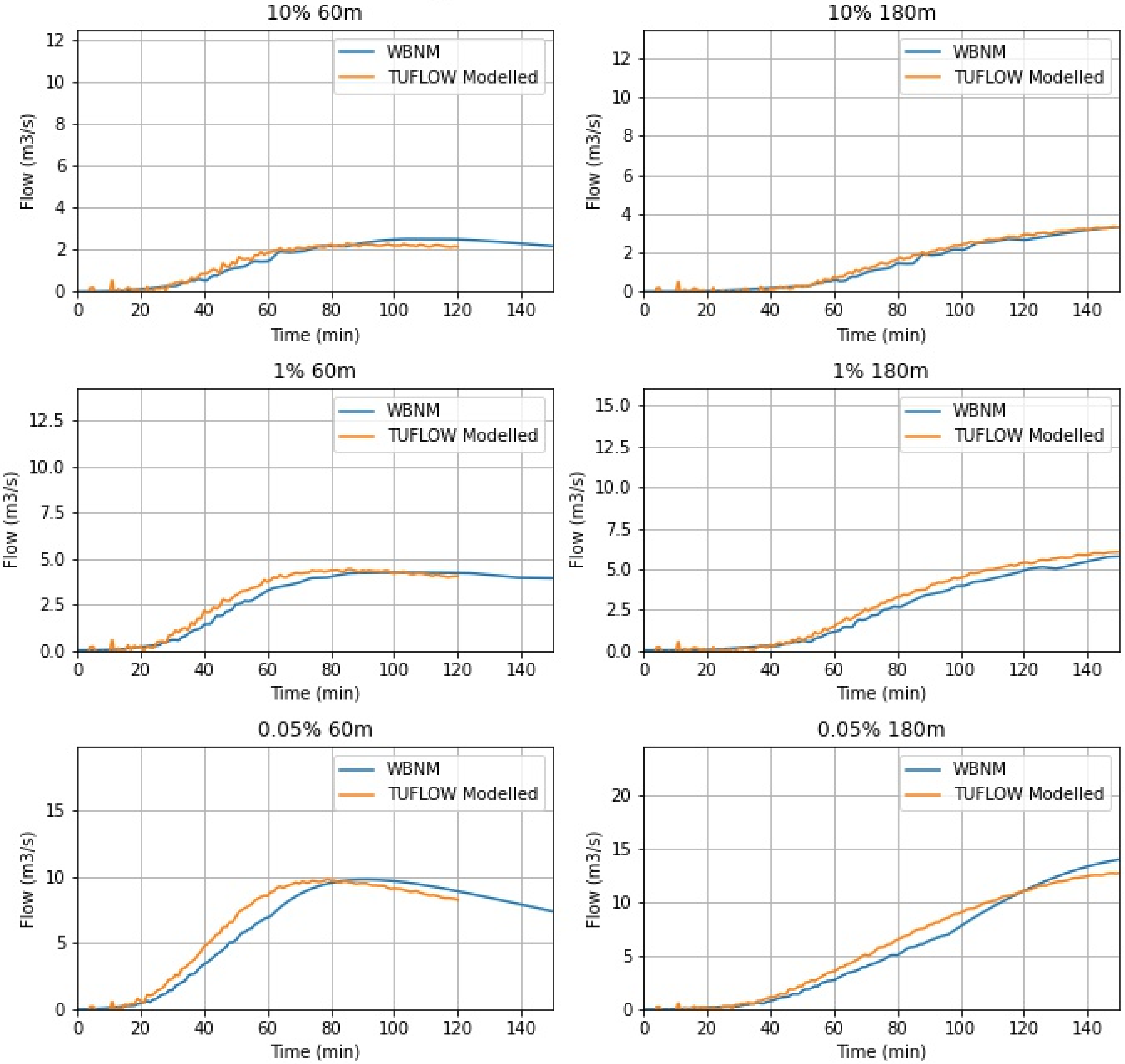
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	2.96%	2.0	0.98
10% 180m	3.03%	3.0	0.96
1% 60m	5.62%	4.0	0.98
1% 180m	0.32%	1.0	0.98
0.05% 60m	8.39%	6.0	0.92
0.05% 180m	0.95%	2.0	0.99

RCN002_00777 HEH Modelling



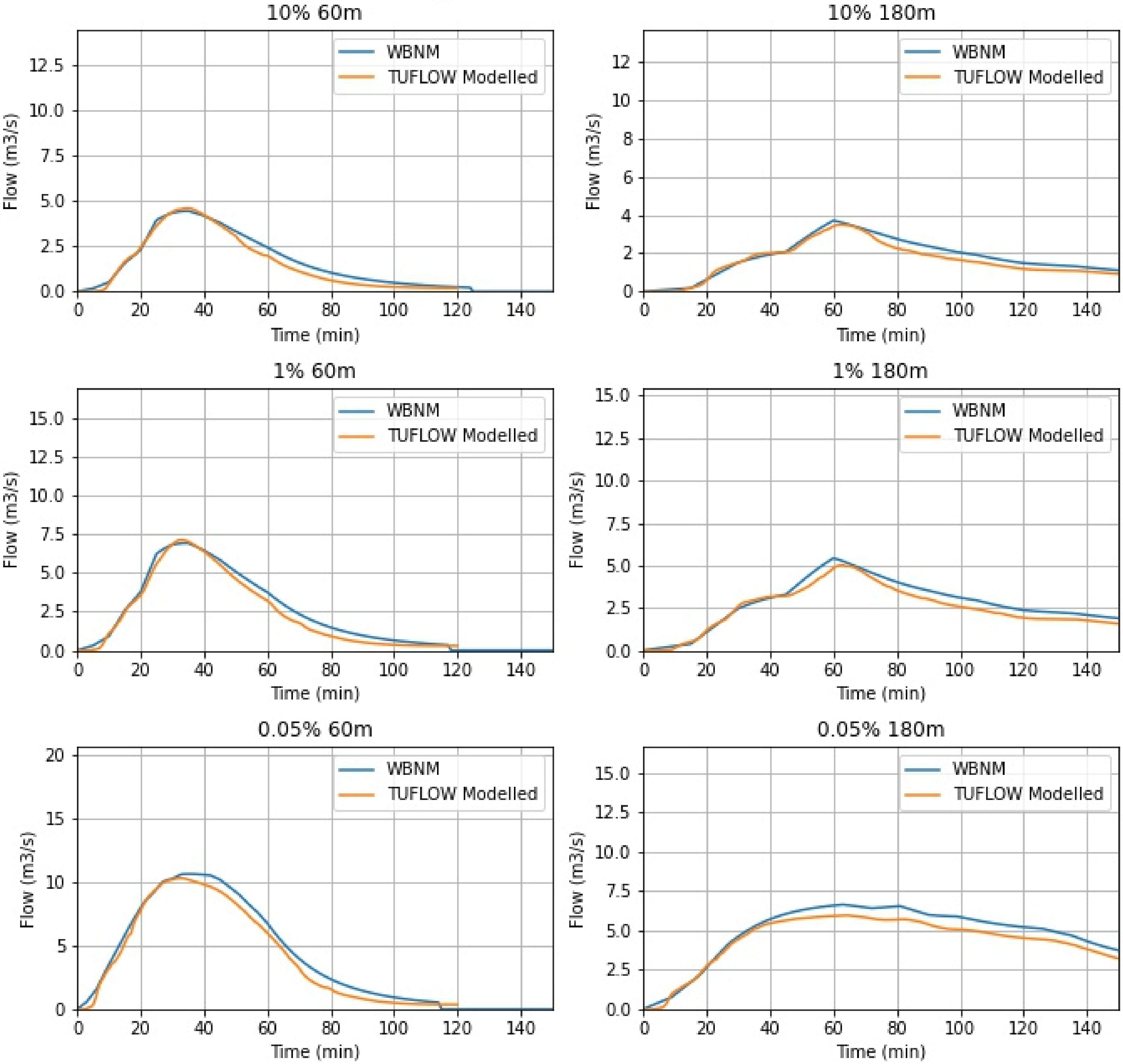
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	12.56%	2.0	0.97
10% 180m	5.81%	4.0	0.96
1% 60m	2.93%	2.0	0.99
1% 180m	3.72%	4.0	0.98
0.05% 60m	20.11%	5.0	0.9
0.05% 180m	8.28%	12.0	0.96

RCN007_00000 HEH Modelling



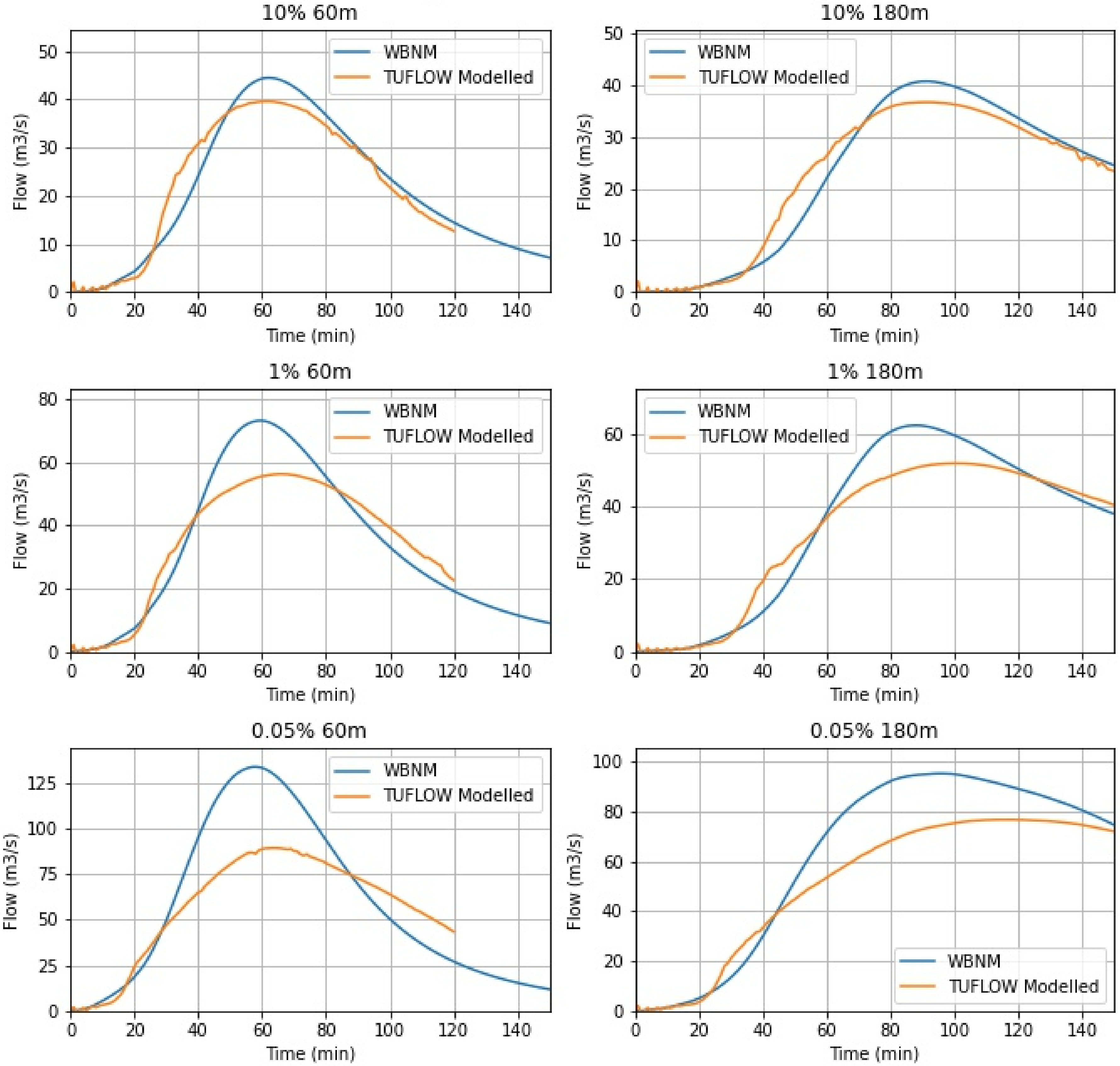
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	8.37%	22.0	0.93
10% 180m	0.72%	11.0	0.96
1% 60m	4.34%	15.0	0.95
1% 180m	2.28%	18.0	0.96
0.05% 60m	0.28%	12.0	0.94
0.05% 180m	11.35%	7.0	0.95

RCN016_00223 HEH Modelling



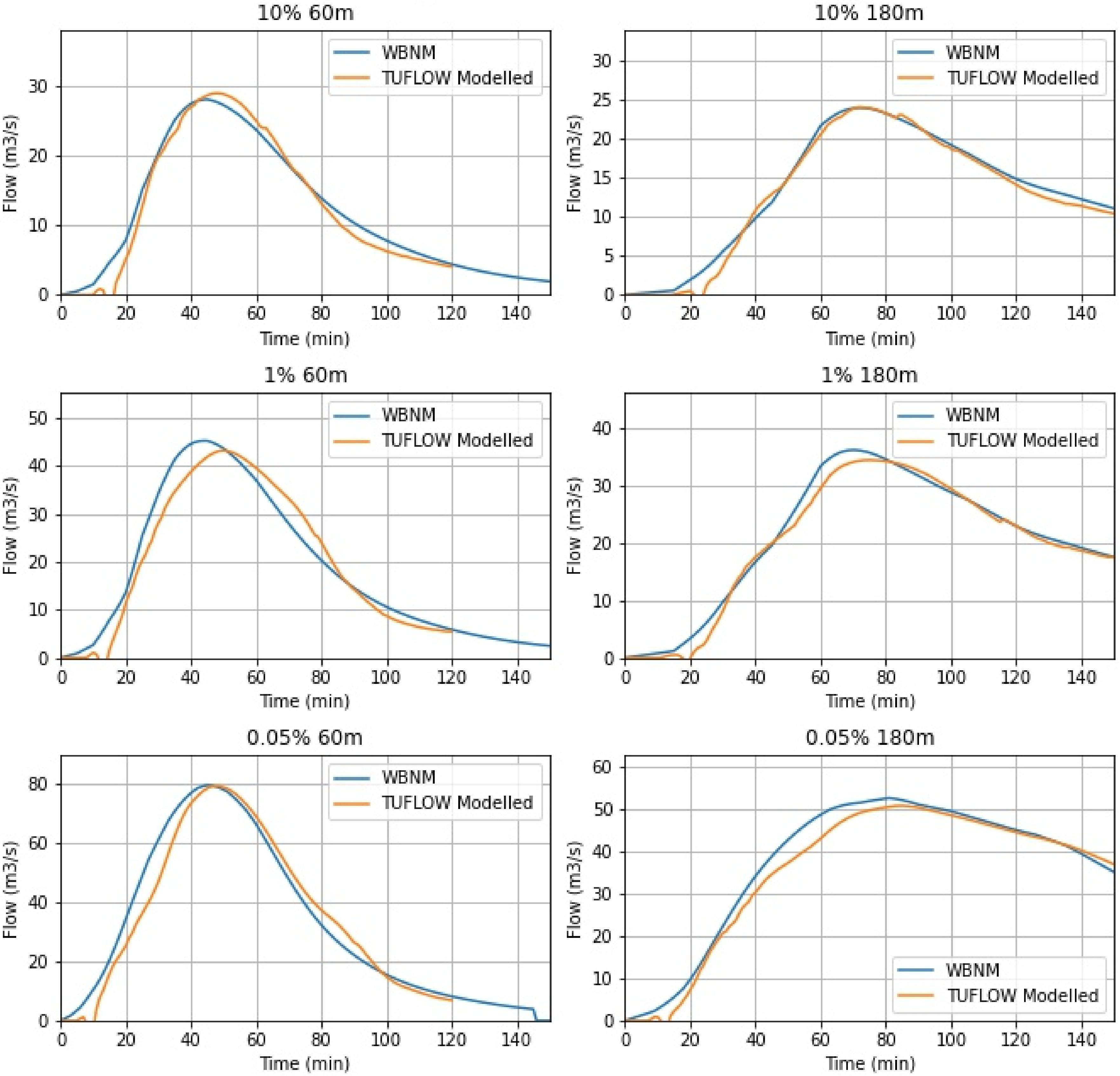
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	3.58%	0.0	0.96
10% 180m	6.0%	2.0	0.93
1% 60m	2.93%	2.0	0.97
1% 180m	7.71%	3.0	0.93
0.05% 60m	3.11%	2.0	0.97
0.05% 180m	10.28%	1.0	0.91

RCS001_00000 HEH Modelling



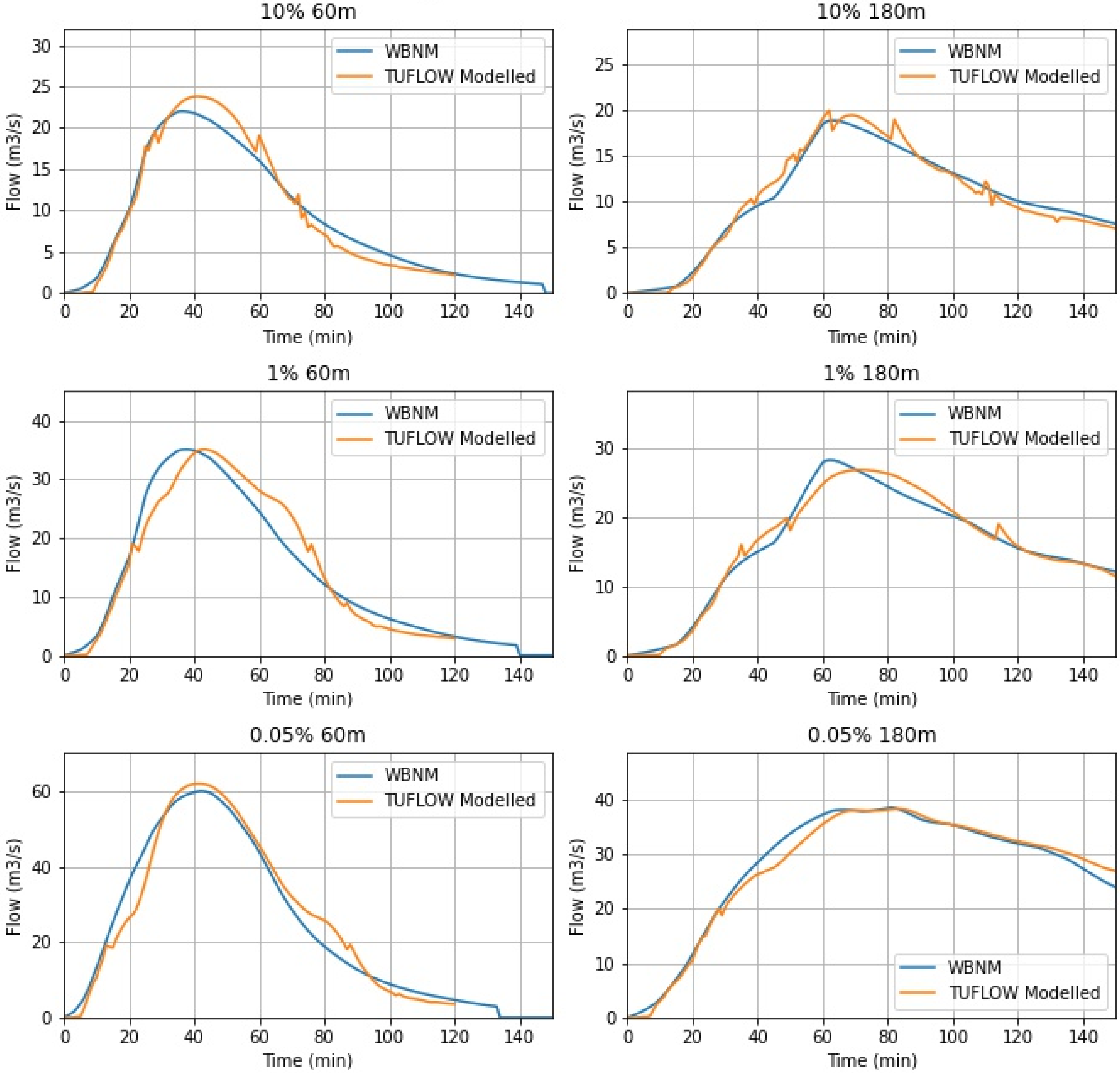
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	10.99%	1.0	0.94
10% 180m	9.95%	1.0	0.95
1% 60m	23.11%	6.0	0.82
1% 180m	16.78%	13.0	0.9
0.05% 60m	33.22%	5.0	0.37
0.05% 180m	19.39%	20.0	0.75

RCS001_00906 HEH Modelling



	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	3.19%	3.0	0.97
10% 180m	0.46%	0.0	0.99
1% 60m	4.55%	6.0	0.94
1% 180m	4.83%	5.0	0.98
0.05% 60m	0.33%	3.0	0.95
0.05% 180m	3.5%	4.0	0.97

RCS001_01556 HEH Modelling


10% 60m

10% 180m

1% 60m

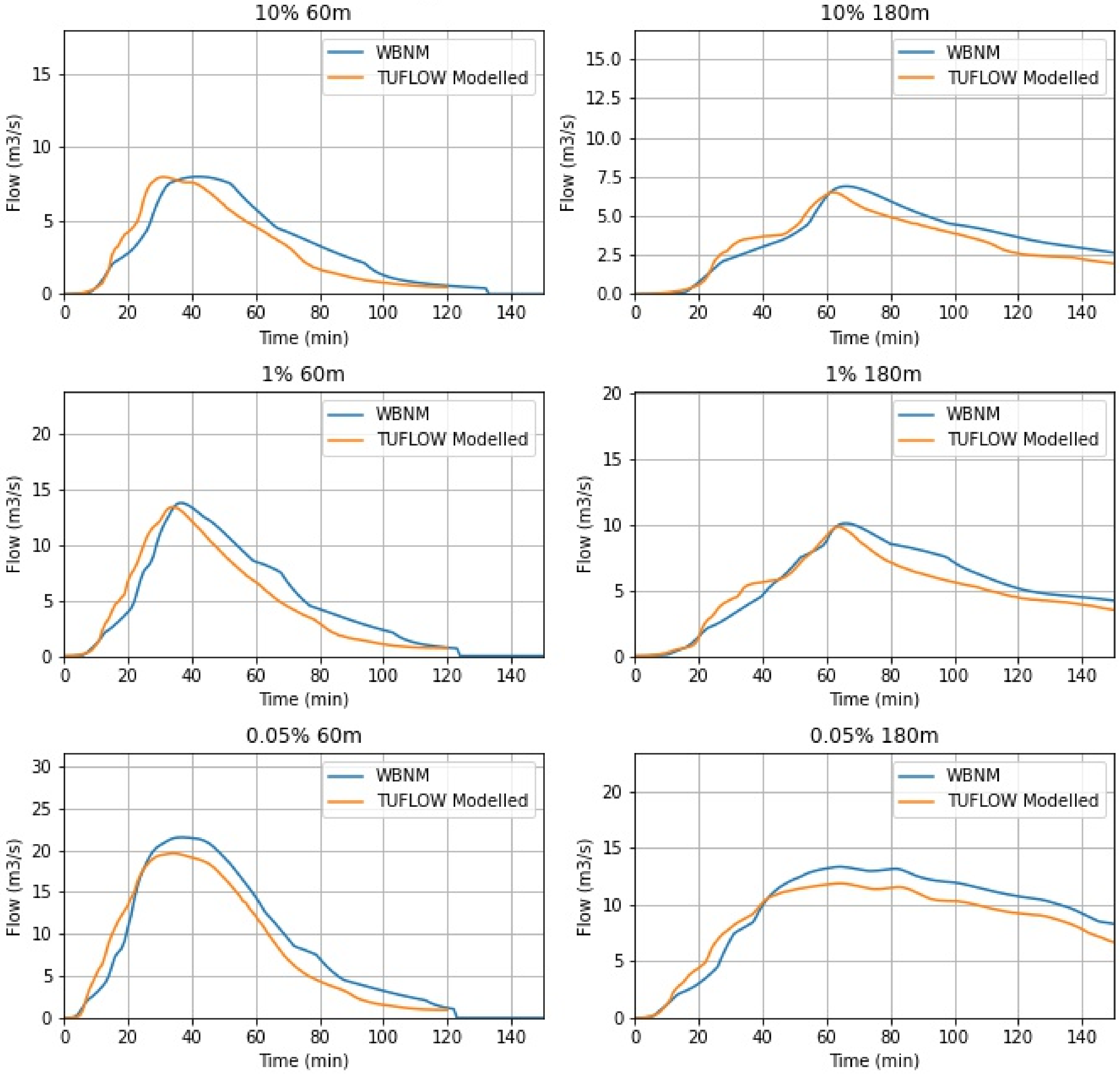
1% 180m

0.05% 60m

0.05% 180m

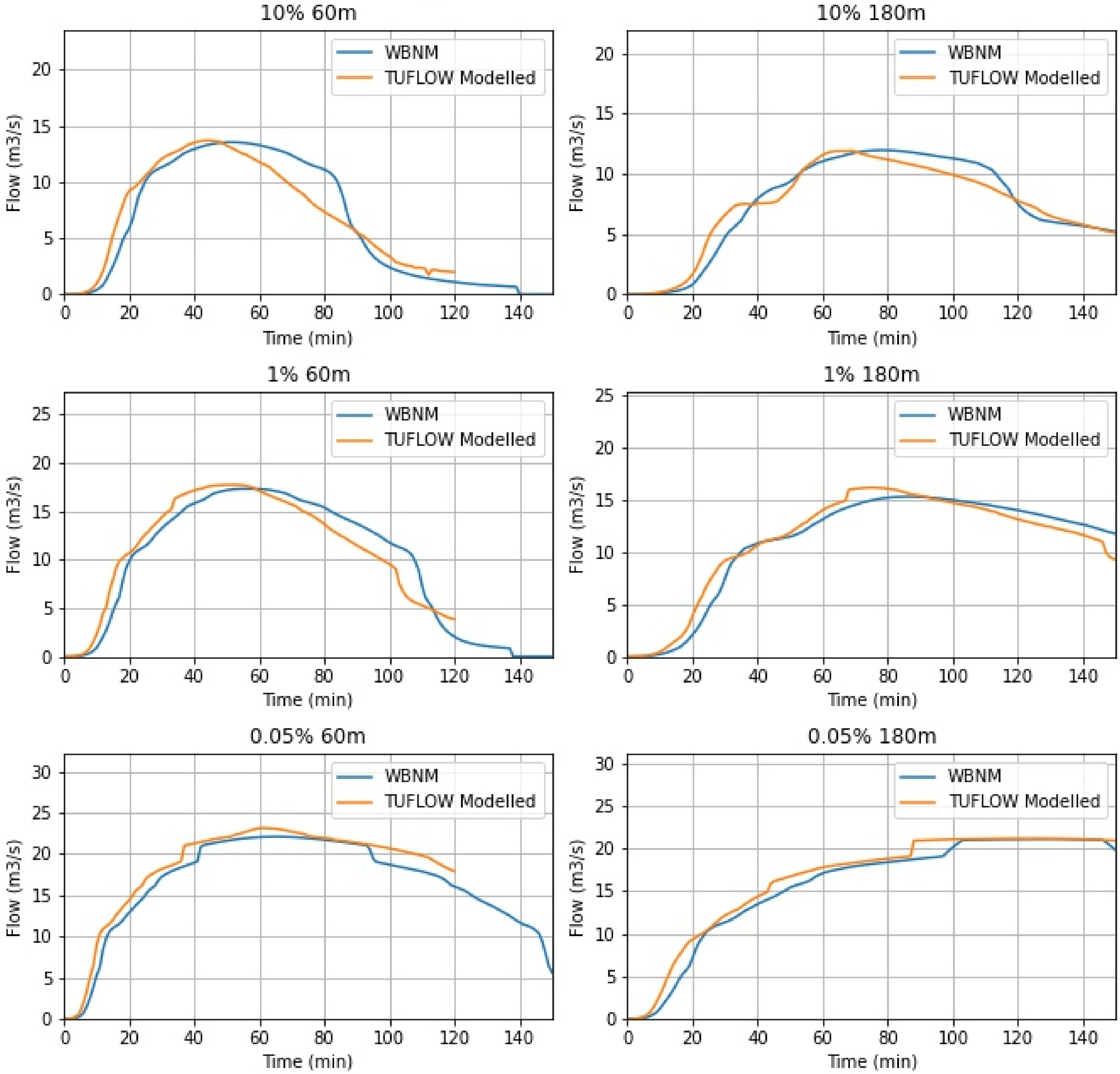
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	8.08%	5.0	0.97
10% 180m	5.61%	1.0	0.98
1% 60m	0.11%	6.0	0.94
1% 180m	4.92%	10.0	0.98
0.05% 60m	3.12%	1.0	0.96
0.05% 180m	0.55%	2.0	0.99

RCS001_02198 HEH Modelling



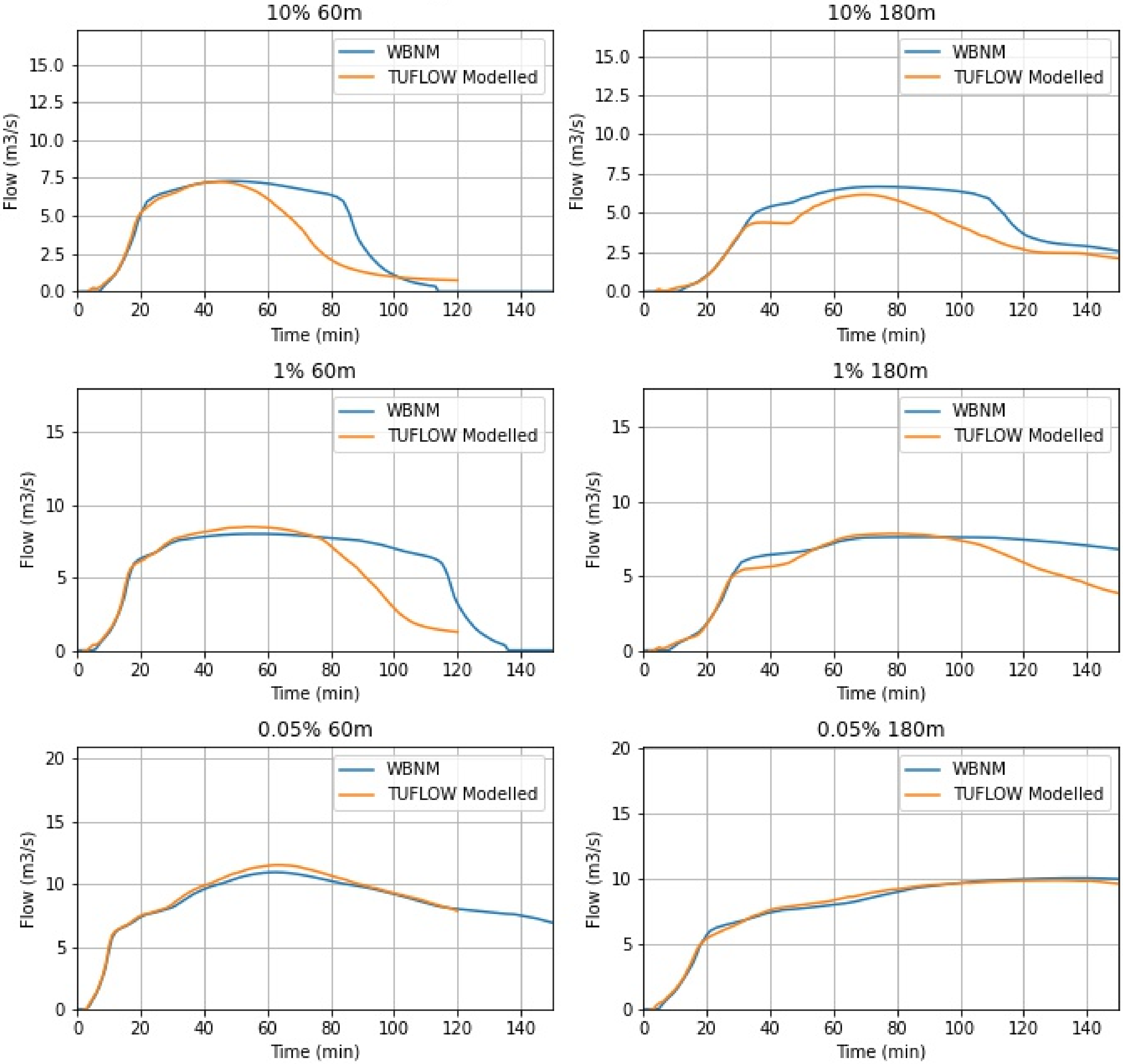
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	0.29%	11.0	0.83
10% 180m	5.66%	4.0	0.87
1% 60m	2.55%	3.0	0.87
1% 180m	2.53%	2.0	0.86
0.05% 60m	8.89%	3.0	0.92
0.05% 180m	11.05%	0.0	0.87

RCS009_00065 HEH Modelling



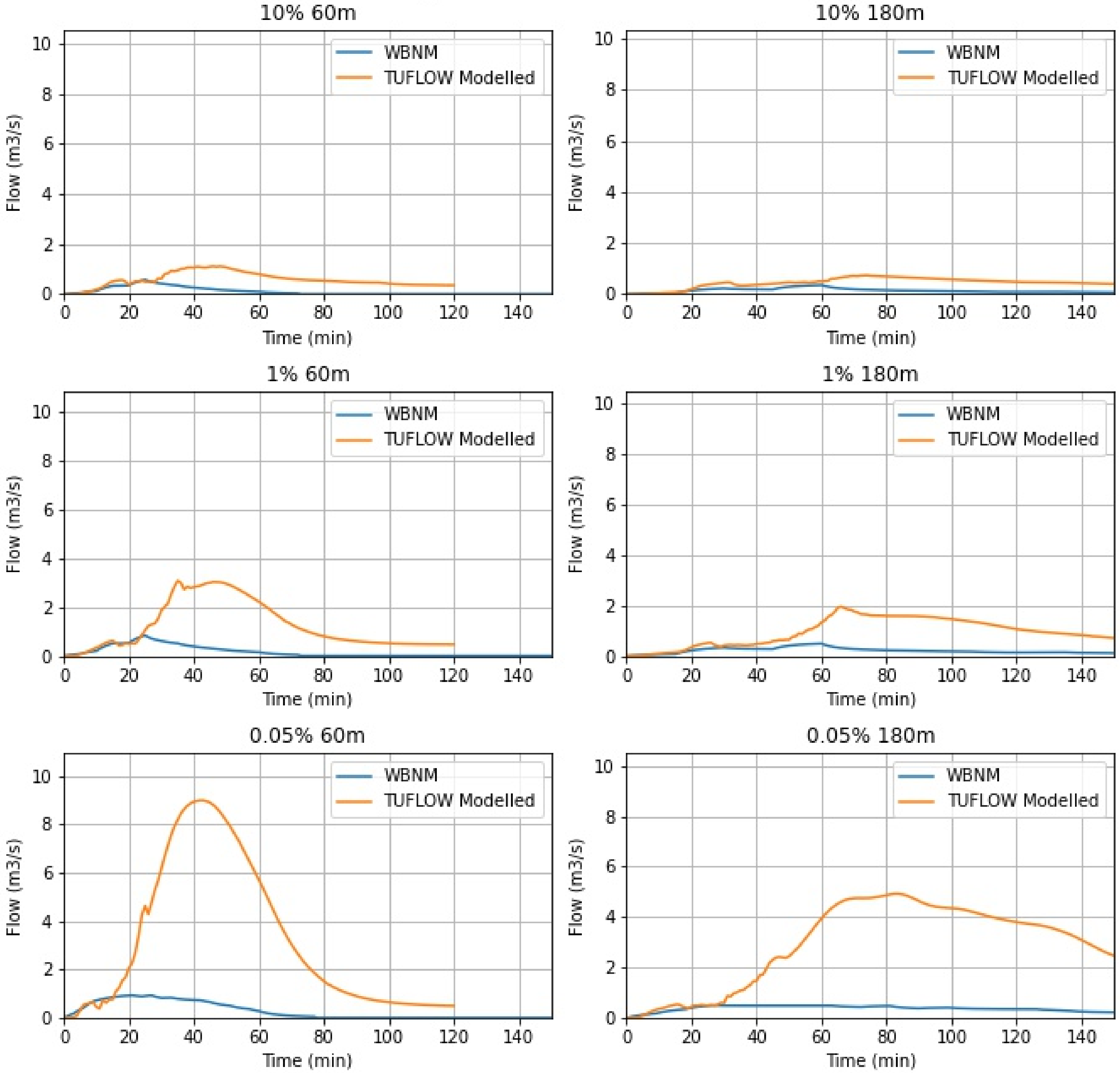
	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	1.15%	7.0	0.86
10% 180m	0.36%	9.0	0.93
1% 60m	2.33%	4.0	0.89
1% 180m	5.67%	11.0	0.97
0.05% 60m	4.72%	4.0	0.95
0.05% 180m	0.43%	5.0	0.96

RCS010_00195 HEH Modelling



	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	0.69%	4.0	0.66
10% 180m	7.63%	4.0	0.7
1% 60m	6.01%	2.0	0.54
1% 180m	2.98%	6.0	0.97
0.05% 60m	5.33%	2.0	0.99
0.05% 180m	1.74%	7.0	0.99

RCS027_00089 HEH Modelling



	Peak diff (%)	Peak timing diff (min)	NSE
10% 60m	93.53%	23.0	0.02
10% 180m	109.12%	14.0	0.06
1% 60m	266.47%	10.0	0.05
1% 180m	301.03%	6.0	0.03
0.05% 60m	870.95%	21.0	0.06
0.05% 180m	896.76%	56.0	0.01

APPENDIX D
POI ARF CLASSIFICATION

POI ID	Area km^2	ARF class
RCS027_00089	0.01	A
RCE004_00173	0.13	A
RCN016_00223	0.20	A
RCE025_00000	0.27	A
RCE009_00000	0.35	A
RCE010_00265	0.35	A
RCE008_00454	0.36	A
RCS001_02198	0.41	A
RCE010_00000	0.42	A
RCS010_00195	0.47	A
RCE008_00000	0.52	A
RCE003_00071	0.77	A
RCS009_00065	0.85	A
RCE001_01440	0.86	A
RCN002_00777	0.96	A
RCN007_00000	1.02	A
RCE001_01082	1.02	A
RCS001_01556	1.20	A
RCS001_00906	1.66	A
RCE001_00000	1.94	B
RCN001_01427	2.39	B
RCS001_00000	3.11	B
RCN001_00000	7.77	B

APPENDIX E
HEH METHODOLOGY MEMO

BMT Commercial Australia Pty Ltd
Level 5, 348 Edward Street,
Brisbane, Qld, 4000
Australia

ABN: 54 010 830 421

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.

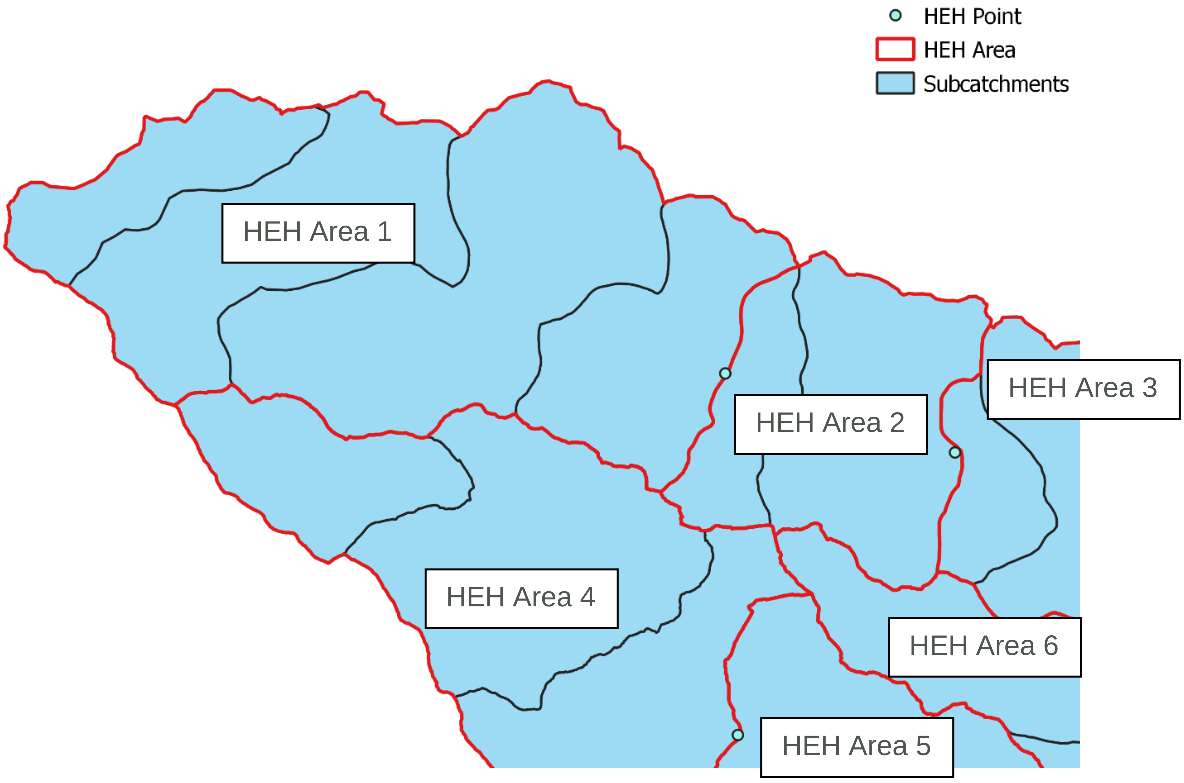

Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

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.

---

[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).

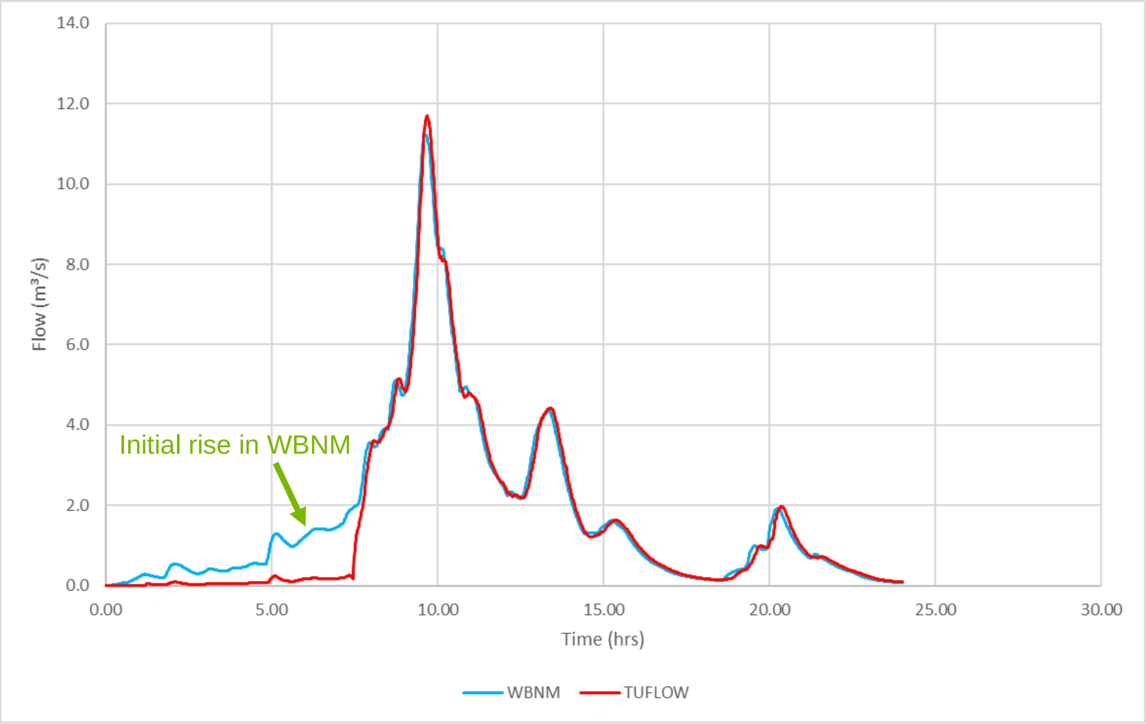

Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

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

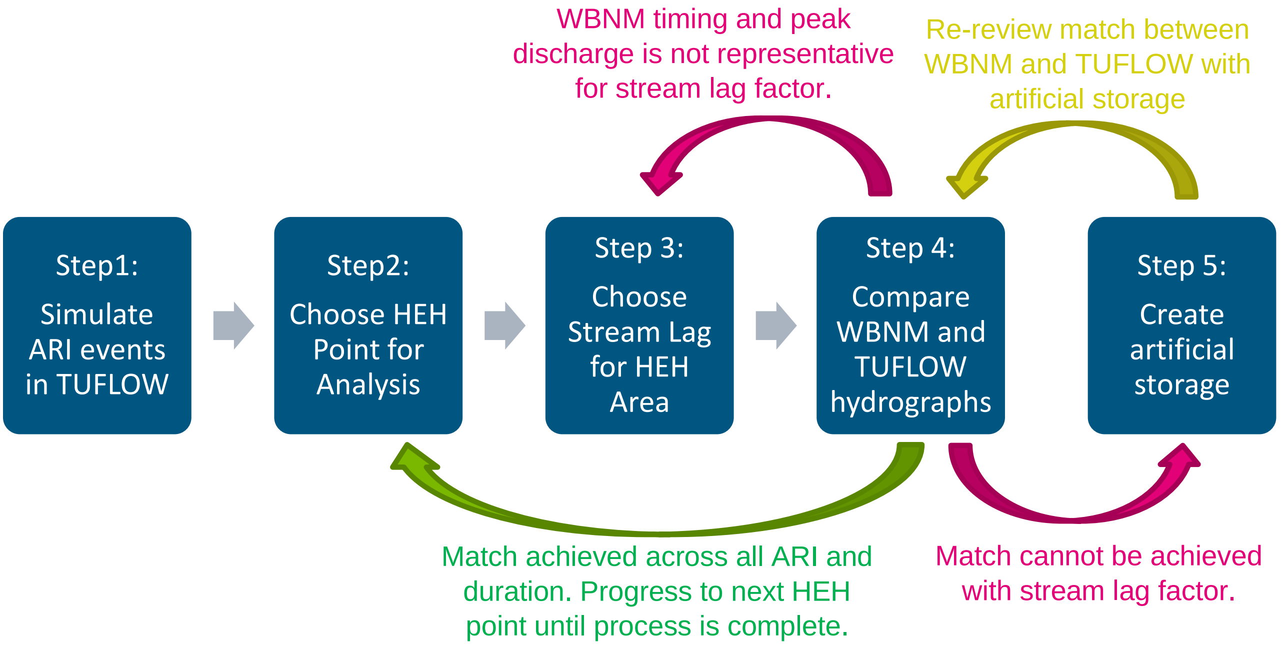


Figure 1.3 Flow chart for the HEH model methodology

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.

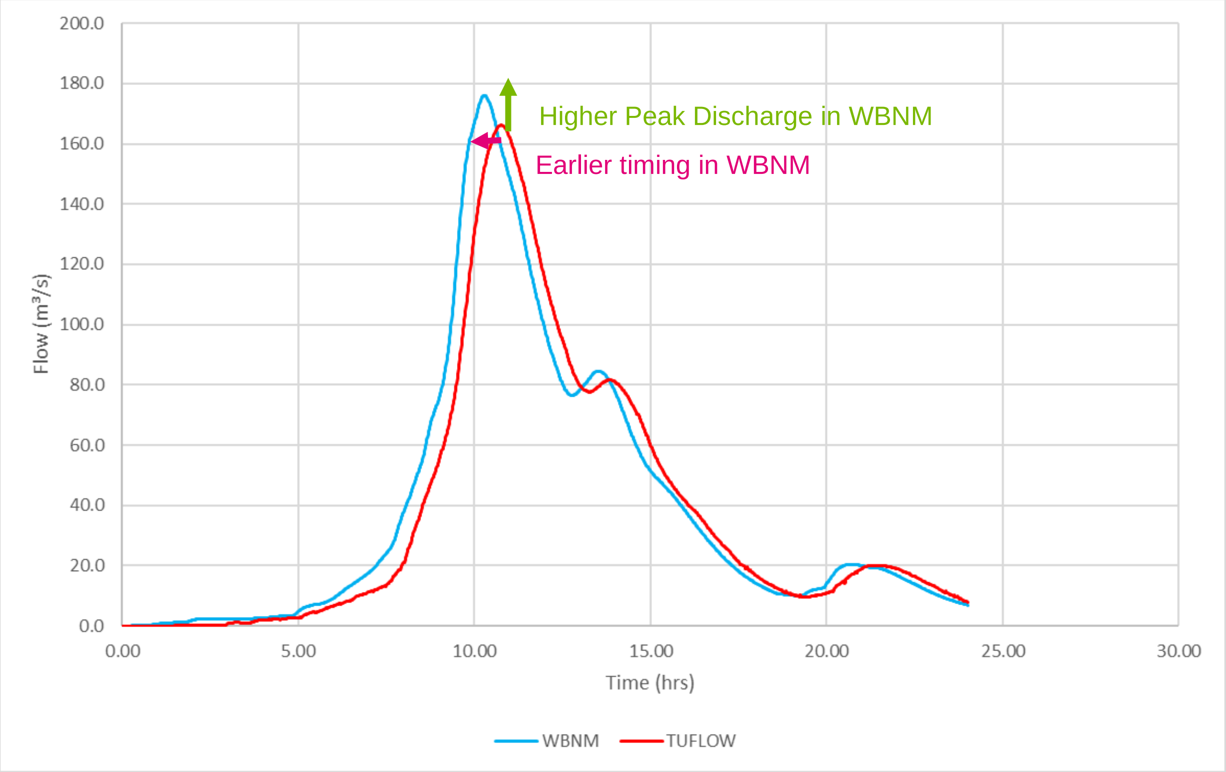


Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

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:

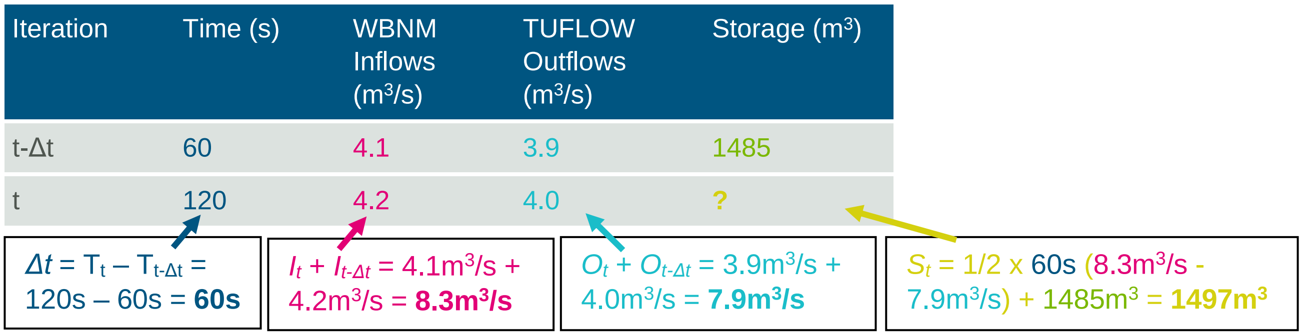
$$\frac{1}{2}\Delta t\left((I_t + I_{t-\Delta t}) - (Q_t + Q_{t-\Delta t})\right) + S_{t-\Delta t} = S_t \tag{1}$$

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.

---

[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.

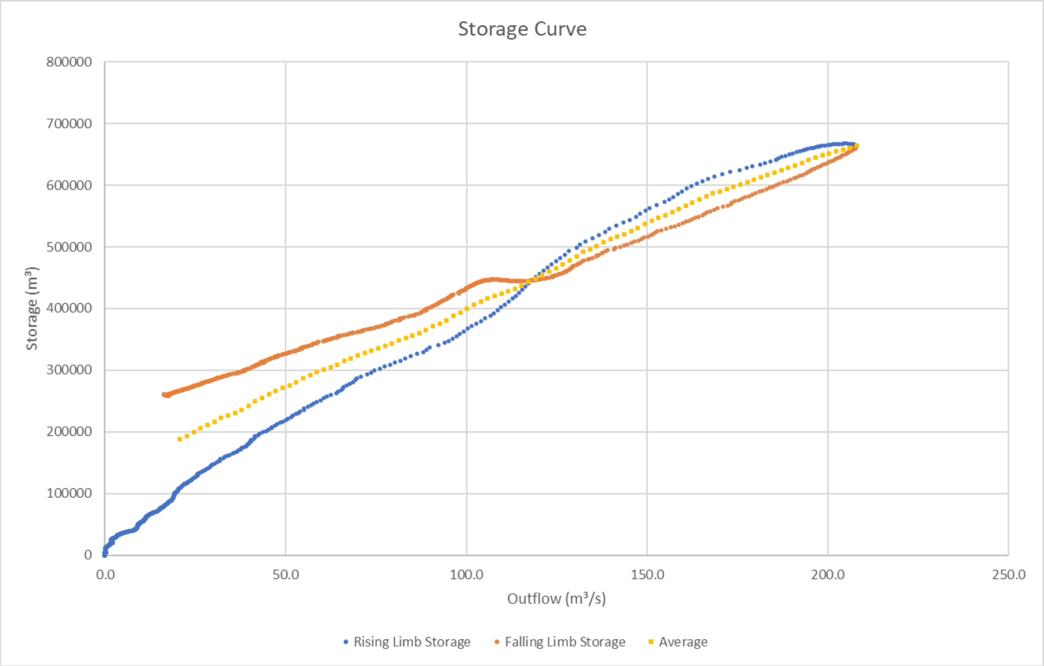
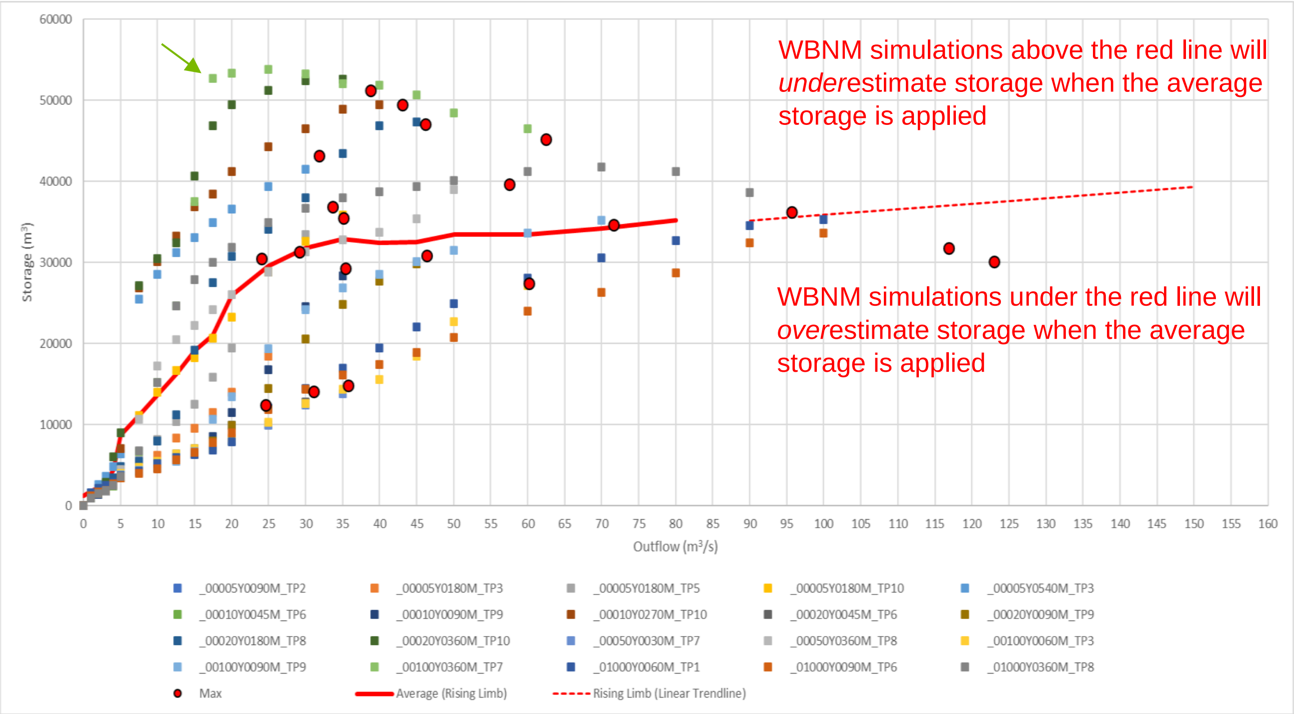


Figure 1.6 Ideal Storage-Outflow Curve

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.

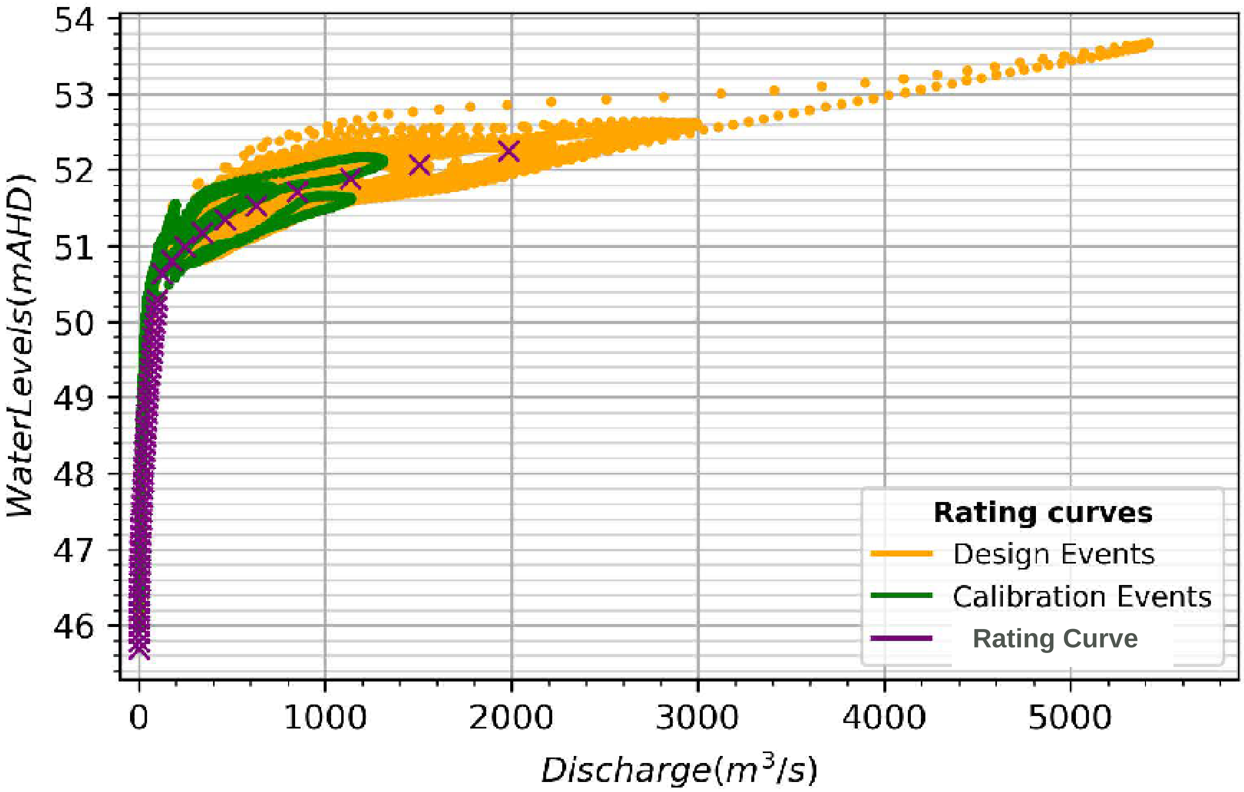


Figure 1.8 Rating curve with hysteresis

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