Regional Flood Database:

2022 Major Model Update - Pumicestone Passage

Moreton Bay Regional Council

Document Status

Version	Doc type	Reviewed by	Approved by	Date issued
V01	DRAFT	Carl Wallis	Alister Daly	28 July 2023
V02	FINAL	Carl Wallis	Alister Daly	8 September 2023
V03	FINAL	Carl Wallis	Alister Daly	4 October 2023

Project Details

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Document Number	22020122_R01_V03_PUM.docx

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Quality ISO 9001 SAI GLOBAL
Environment ISO 14001 SAI GLOBAL
OHS ISO 45001 SAI GLOBAL

CONTENTS

1	INTRODUCTION	5
2	BACKGROUND	6
2.1	Catchment Description	6
3	2022 MAJOR FLOOD MODEL UPDATE DETAILS	7
3.1	ARR 2019	7
3.2	Rainfall Intensity-Frequency-Duration (IFD) Update	7
3.2.1	Intensities	7
3.2.2	AR&R 2019 Datahub	8
3.3	WBNM Hydrological Model Update	8
3.3.1	Subcatchment Updates	8
3.3.2	Impervious Areas	8
3.3.3	Parameters	8
3.3.4	Areal Reduction Factors	9
3.3.5	Preburst Application	9
3.3.6	Future Climate	9
3.3.7	Design Event Rainfall Losses	9
3.4	TUFLOW Hydraulic Model Update	10
3.4.1	Model Layout and Extents	10
3.4.2	Model Topography	12
3.4.3	Floodplain Structures	12
3.4.4	Floodplain Roughness	16
3.4.5	Inflow Boundaries	17
3.4.6	Tailwater Boundaries	18
4	MODEL METHODOLOGY AND SIMULATIONS	21
4.1	Validation to Historical Events	21
4.1.1	Rainfall Data Available	21
4.1.2	Stream Guage Data Available	21
4.1.3	Flood Debris Marks Available	23
4.1.4	Losses and Catchment Parameters	23
4.2	Hydraulic Equivalent Hydrologic (HEH) Model development	23
4.2.1	Points of Interest	23
4.2.2	Methodology	26
4.3	TUFLOW Hydraulic Model	26
4.3.1	Adopted Design Tailwater Conditions	26
4.3.2	Design Event Structure Blockage	26
4.3.3	Model Simulations	27
5	MODEL RESULTS AND OUTCOMES	28
5.1	TUFLOW Hydraulic Model Validation	28
5.1.1	February 2015	28
5.1.2	May 2015	30
5.1.3	February 2022	33

5.1.4 Summary 35
5.2 WBNM Hydraulic Equivalent Hydrologic Model performance 36
5.2.1 Critical Storm Selection 36
5.3 Design Flood Behaviour 38
5.3.1 Peak Flow Comparison 38
5.3.2 Comparison to RFD 2014 39
5.4 Model Limitations and Quality 42
5.5 Model Specification and Run Times 43
6 CONCLUSION 44
7 DISCUSSION 44
8 REFERENCES 45

APPENDICES

Appendix A POI ARF Classification
Appendix B Flood Mark Analysis
Appendix C HEH Plots and Summary Tables
Appendix D BMT HEH Methodology Memorandum
Appendix E Calibration and Validation Memorandum

LIST OF FIGURES

Figure 1-1 Pumicestone Passage Locality 5
Figure 3-1 Hydraulic model extent change 11
Figure 3-2 Pedestrian bridge adjacent to Bribie Island Road observed on site visit 13
Figure 3-3 Trunk Drainage Comparison 2014 Model v 2022 Model 14
Figure 3-4 Missing structure details – Ningi Waters Drive 15
Figure 3-5 Missing structure details – Upgraded Bruce Highway 16
Figure 3-6 Depth varying Manning’s values 17
Figure 3-7 Hydraulic Model Roughness Layout 19
Figure 3-8 Hydraulic model trunk network and inflow boundaries 20
Figure 4-1 Rainfall and Stream Gauge Locations 22
Figure 4-2 Point of Interest locations 25
Figure 5-1 Pumicestone Passage February 2015 – extent and debris locations 29
Figure 5-2 February 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert 30
Figure 5-3 February 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert 30
Figure 5-4 Pumicestone Passage May 2015 – extent and debris locations 31
Figure 5-5 May 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert 32
Figure 5-6 May 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert 33
Figure 5-7 Pumicestone Passage February 2022 – extent and debris locations 34
Figure 5-8 February 2022 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert 35
Figure 5-9 February 2022 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert 35
Figure 5-10 RFD 2022 minus RFD 2014 1% AEP peak flood level (unblocked) 40

Figure 5-11 RFD 2022 minus RFD 2014 1% AEP DFE peak flood level (future climate) 41
Figure 5-12 TUFLOW Control Numbers and Timestep 43

LIST OF TABLES

Table 3-1 ARR 2019 DataHub Parameters 8
Table 3-2 ARF classification table 9
Table 3-3 Preburst temporal pattern 9
Table 3-4 TUFLOW materials roughness values 16
Table 4-1 Rainfall Gauges Used for Validation 21
Table 4-2 Stream Gauges Used for Validation 21
Table 4-3 Debris mark availability summary 23
Table 4-4 Validation events – WBNM adopted parameters 23
Table 4-5 Blockage matrix 27
Table 5-1 Critical Events Selected 37
Table 5-2 Peak Flow Over/Underestimation at POIs 37
Table 5-3 1% AEP WBNM vs TUFLOW Peak Flow Comparison 38
Table 5-4 Pumicestone Passage model specification and run times 43

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 Floodplain 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. This report details the outcomes of Stages 4 and 5 of the MBRC RFD for the Pumicestone Passage (PUM) Catchment. Figure 1-1 presents the location of the Pumicestone Passage 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.

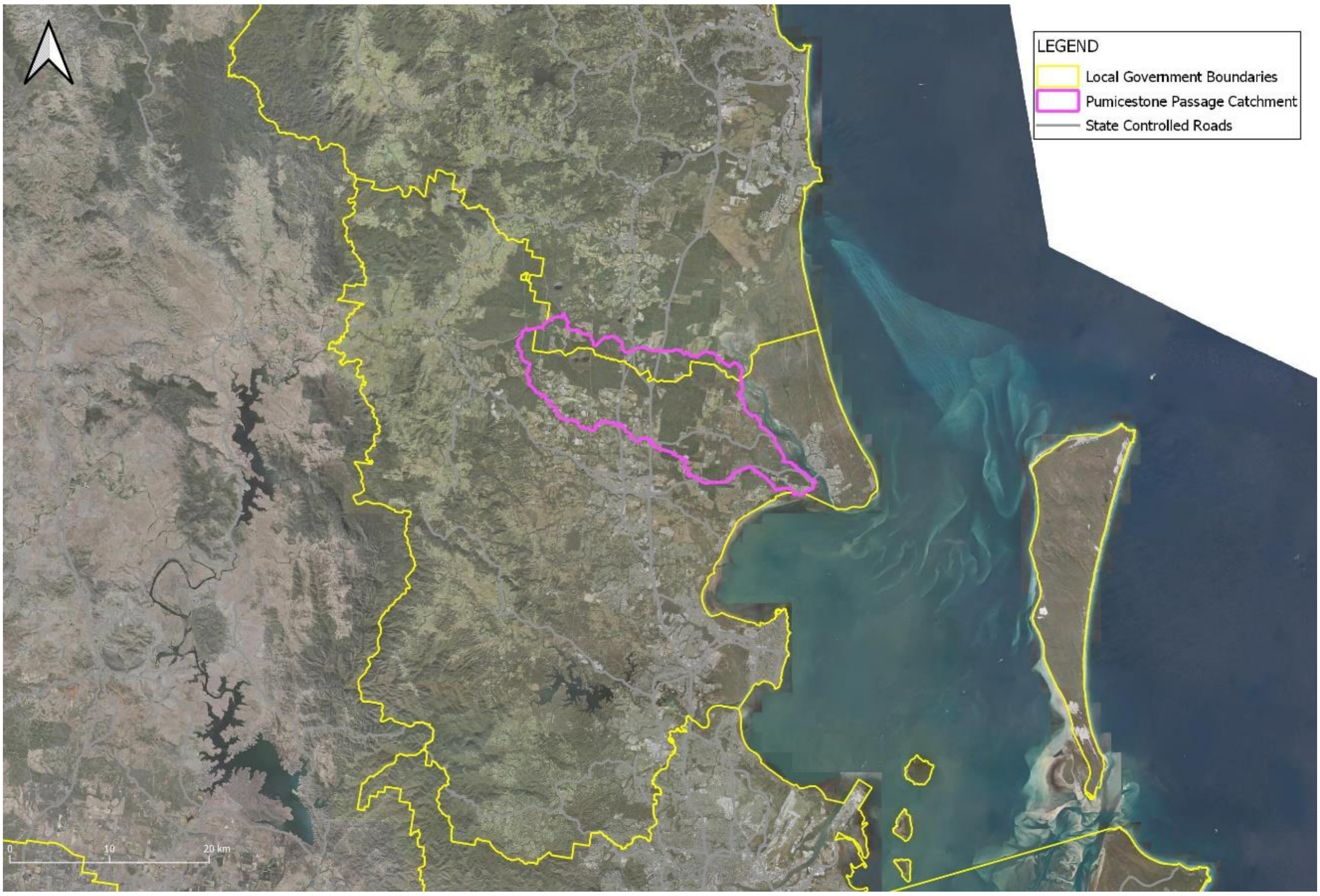

Figure 1-1 Pumicestone Passage Locality

2 BACKGROUND

The methodology behind the RFD is primarily based on the national guideline for flood estimation, Australian Rainfall and Runoff (ARR). This guideline underwent a major revision in 2016 and then a minor update in 2019. The updated guideline, together with recently collected LiDAR 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 landuse roughness layers, catchment delineation and hydrology models.
- ***Stage 3 - Hydraulic model configuration investigation*** - was an internal investigation conducted by Council 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 Pumicestone Passage Catchment.

2.1 Catchment Description

The Pumicestone Passage catchment is typified by linear flowpaths and watercourses upstream (west) of the Bruce Highway which drain the largely undeveloped upper catchment to the outlets which are low-lying and dominated by tidal ingress. Land-use within the Pumicestone Passage catchment is largely rural with isolated pockets of medium residential development, typically located in close proximity to major roadways such as the Bruce Highway and Bribie Island Road.

The Pumicestone Passage catchment is traversed by several designated watercourses, namely:

- Ningi Creek
- Elimbah Creek
- Six Mile Creek
- Beerburrum Creek
- Glass House Mountain Creek

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

3.2.2 AR&R 2019 Datahub

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

Table 3-1 ARR 2019 DataHub Parameters

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

3.3 WBNM Hydrological Model Update

3.3.1 Subcatchment Updates

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

3.3.2 Impervious Areas

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

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

3.3.3 Parameters

The Pumicestone Passage catchment WBNM model has adopted the following runoff routing parameters.

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

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

3.3.4 Areal Reduction Factors

The pilot study recommended that the ARF be calculated at each Point of Interest (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 Pumicestone Passage model including the subsequent area and ARF category applied for the design event modelling. Appendix A 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	10	0km^2 to 20km^2	8km^2	Point
ARFb	6	20km^2 to 35km^2	27km^2	Point
ARFc	5	35km^2 to 70km^2	50km^2	Point
ARFd	5	70km^2 to 100km^2	85km^2	Point
ARFe	0	100km^2 to 150km^2	120km^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

Simulations of year 2100 future conditions were performed by adopting the RCP8.5 climate change scenario featuring an increase in rainfall intensity of 20%. 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 4.3.3.2.

3.3.7 Design Event Rainfall Losses

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

3.4 TUFLOW Hydraulic Model Update

To assess the hydraulic characteristics for the Pumicestone Passage 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 Pumicestone Passage model area is characterised by linear flowpaths and watercourses upstream (west) of the Bruce Highway which drain the largely undeveloped upper catchment to the outlets which are low-lying and dominated by tidal ingress.

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.
- New digital elevation models for developments completed after the capture of 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 boundary extent has been modified only slightly from the previous study. This was undertaken to better assess flooding in the upper reaches of watercourses and to remove some glass walling effects. Figure 3-1 shows the TUFLOW model code boundary for both the previous (2014) and updated model (2022). The previously adopted RFD model grid orientation of north-south, with no orientation angle has been maintained.

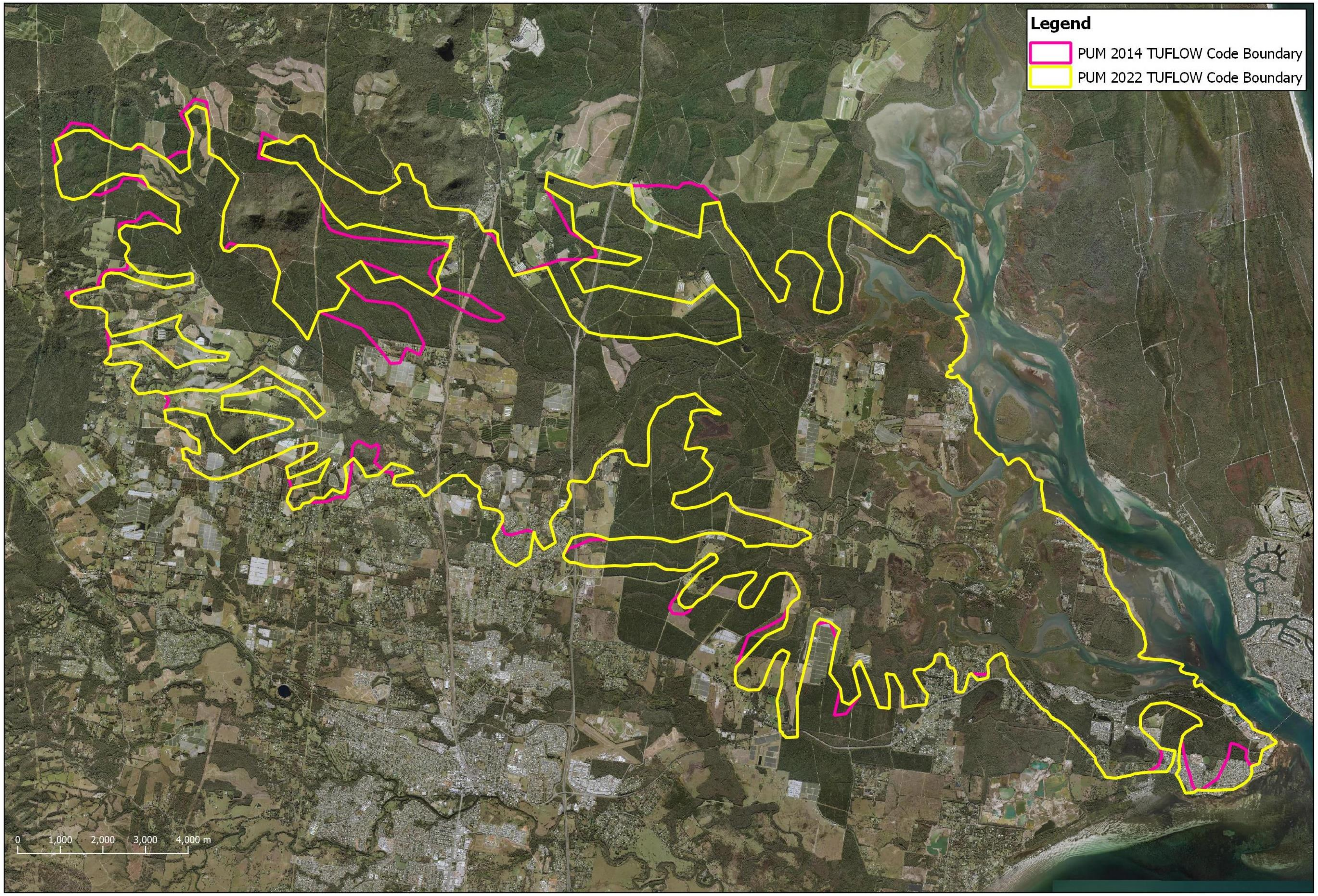

Figure 3-1 Hydraulic model extent change

3.4.2 Model Topography

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

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

The inclusion of earthworks designs from the supplied Bruce Highway Upgrade TUFLOW model was also undertaken. These earthworks include the upgraded road alignment, bridge abutments and drainage infrastructure (bio-basins and drainage channels). It is noted that the earthworks arrangement for the upgraded Bruce Highway was not incorporated into the historical event TUFLOW models.

3.4.3 Floodplain Structures

3.4.3.1 Bridge Structures

A detailed review of all bridge structures and associated model parameters and representation has been undertaken. The key alteration from the previous study is that calculation of losses for 2d_lfcsh is set to ***Portion*** compared to the previous ***Cumulate***. On review of the previous adopted values in the 2d_lfcsh layers it was noted the model was overestimating form losses through structures in layer 1 as values applied had not been divided by 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 1.56, as advised in the Pilot Study, has been adopted through the structures deck.

A pedestrian bridge adjacent to Bribie Island Road at Ningi was identified as not being included in the provided MBRC structure database. This structure has been added to the updated TUFLOW model. With the lack of structure details available several assumptions have been made. Figure 3-2 shows the 2d_lfcsh attributes applied to this footbridge.

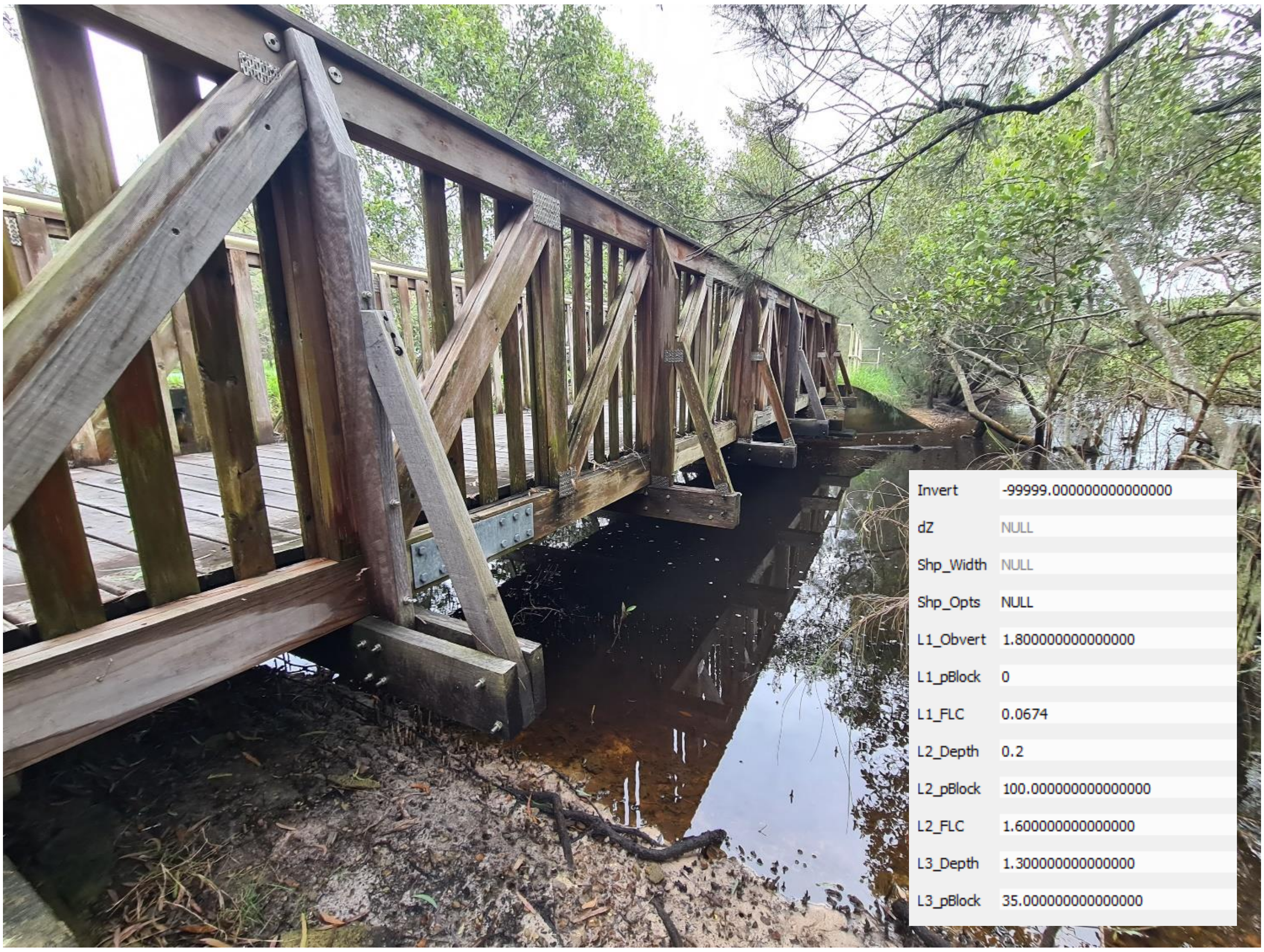

Figure 3-2 Pedestrian bridge adjacent to Bribie Island Road observed on site visit

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 incorrect pipe details (adverse grades) and missing pipes have been updated to better reflect current catchment conditions.

Additional pipes and culverts requested by MBRC as per the project brief have also been added to the model. Updates to the TUFLOW code boundary and subcatchment inflows were also undertaken to accommodate the additional pipes and culverts.

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

The MBRC GIS database for the stormwater network included a significant number of erroneous data points with missing and incorrect invert levels. For the purposes of the TUFLOW modelling missing or incorrect invert levels were estimated by using the nearest correct invert level available and interpolating from the LiDAR to estimate a slope. The 1D network naming convention has been adopted from the 2014 RFD study. Whereby new structures were added, the AssetID of the structure was adopted.

A comparison of the 2014 and 2023 drainage datasets is presented in Figure 3-3.

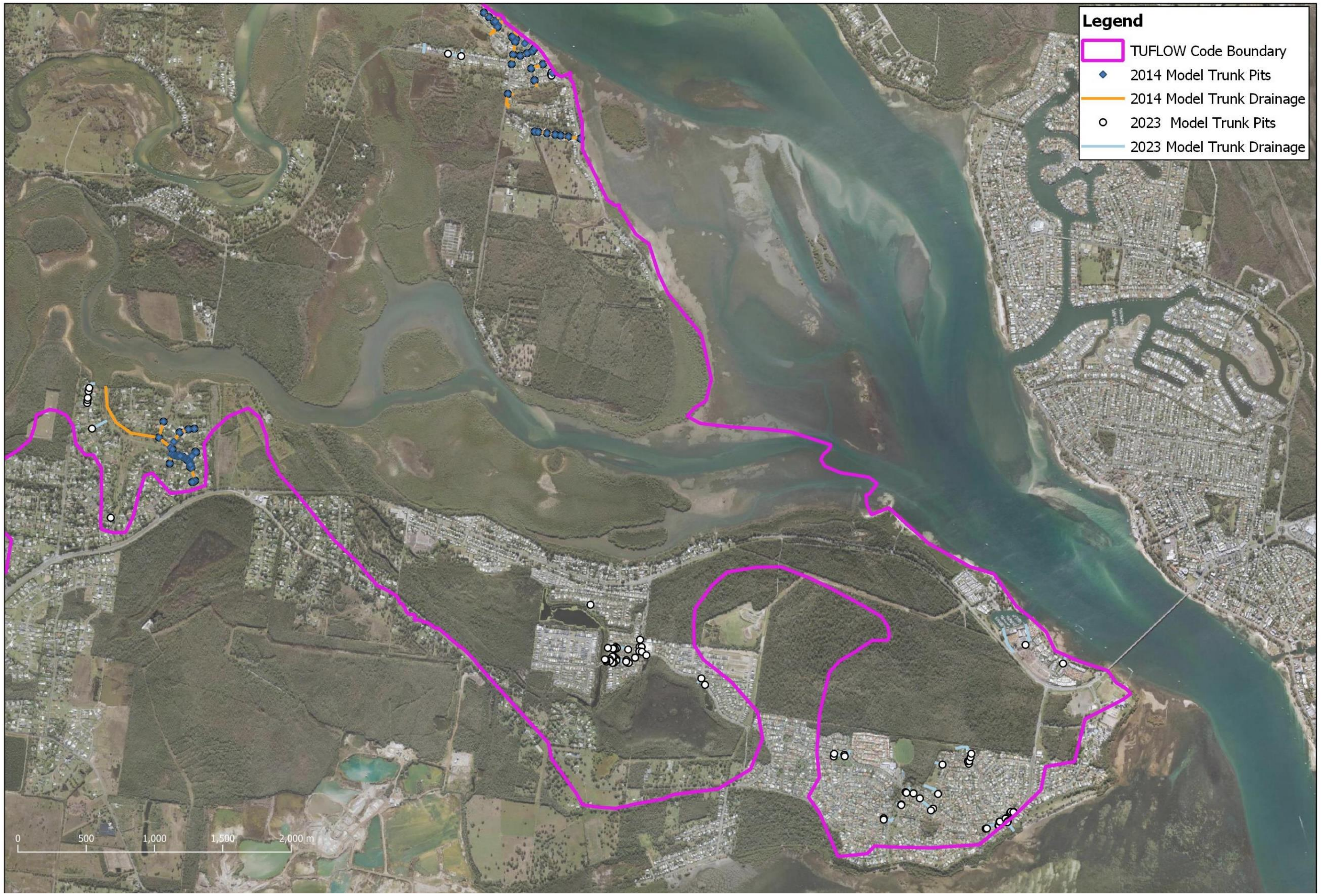

Figure 3-3 Trunk Drainage Comparison 2014 Model v 2022 Model

3.4.3.3 Other Structures

One fauna fence was incorporated in the PUM model along Newlands Road as a layered flow construction. Guard rails were also included as layered flow constrictions. The location and orientation of the fauna fence and guard rails was adopted from the supplied shapefiles.

The bridge/culvert structure crossing the canal estate at Ningi Waters Drive was observed during the site inspection had not been included in the 2014 model. The location of this structure is shown in Figure 3-4. Detailed design drawings of this structure were supplied and it was included as an irregular culvert. Similarly, a missing culvert underneath the upgraded Bruce Highway was identified. This structure was not included in the supplied model files and its lack of inclusion results in water ponding upstream of the upgraded Bruce Highway. The location of this missing structure is presented in Figure 3-5. It was noted that the contributing upstream catchment to this structure is not significant. As such, the inflow was placed downstream of the Bruce Highway to allow for a better representation of flooding behaviour in this section of the model.

Figure 3-4 Missing structure details – Ningi Waters Drive

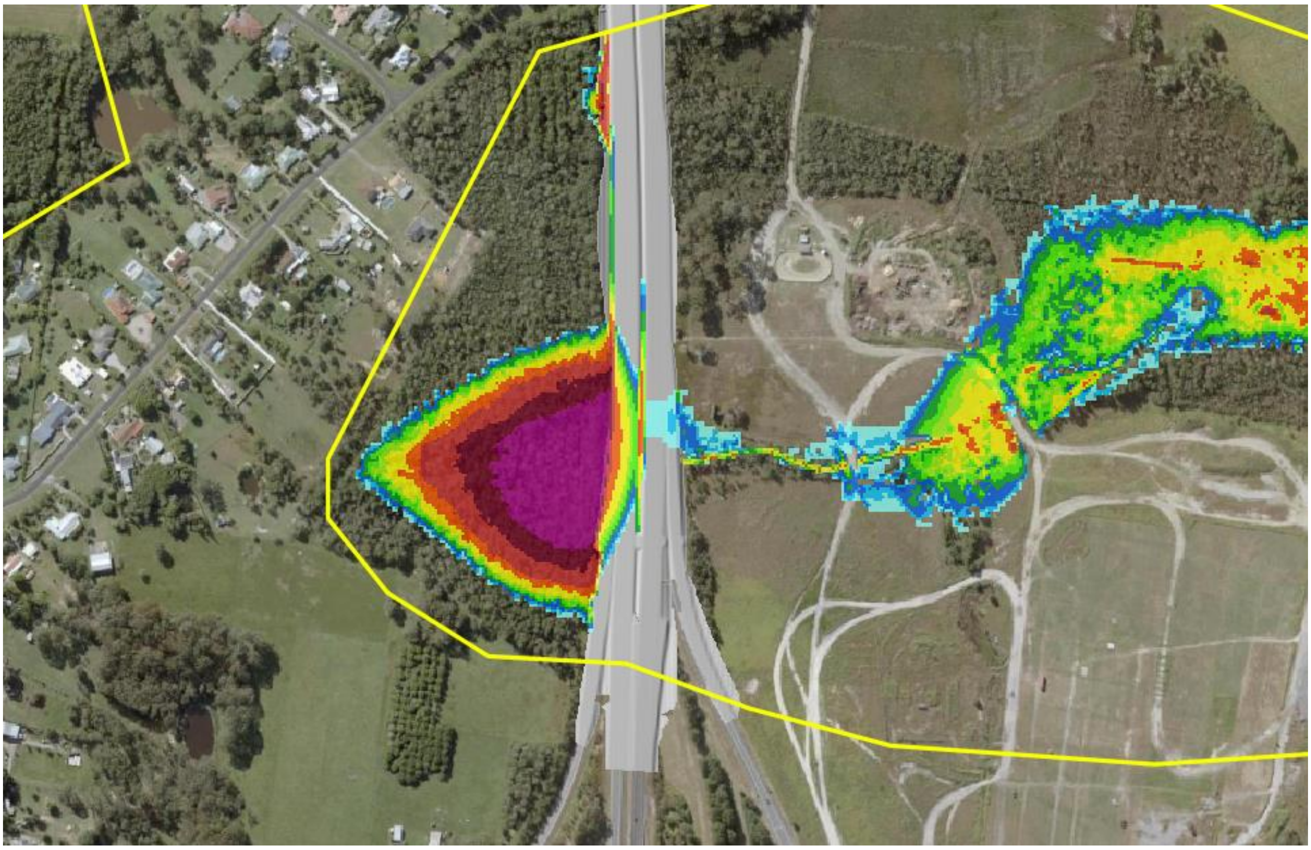

Figure 3-5 Missing structure details – Upgraded Bruce Highway

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 and refined through the calibration process and further validated to comparison of debris marks for three (3) historical flood events in this catchment. Floodplain roughness is visually presented in Figure 3-7.

Table 3-4 TUFLOW materials roughness values

Material ID	Manning's n	Description
1	Low_Grass_Grazing_004.csv	Open Space (grasses)
2	Low_Dense_Vegetation_004.csv	Low Density Understory - Vegetation
3	Medium_Dense_Vegetation_004.csv	Medium density Understory - Vegetation
4	High_Dense_Class2_Vegetation_001.csv	Extreme 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

Material ID	Manning's n	Description
9	0.04	Open Space -Crops (Fallow)
10	0.04	Low Density Understory - Crops
11	0.04	Medium density Understory - Crops
12	0.04	High density understory - Crops
13	0.015	Roads
14	0.015	Concrete
15	0.03	Waterbody
16	0.50	Buildings
17	0.50	Horticulture Buildings
18	0.025	Facilities - tennis/basketball courts and substations
19	0.075	Railways

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 Class 2 Vegetation	
y (m)	n		y (m)	n
0	0.05		0	0.09
1.5	0.05		1.5	0.09
3.5	0.075		3.5	0.18
99	0.075		99	0.18

Figure 3-6 Depth varying Manning's values

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. In areas where the trunk drainage is the main flow path through the catchment, the inflows are distributed to 1D pit nodes as "SA_Pit" polygons. For catchments where a clear creek or channel is the main conveyance a standard SA polygon is applied in which flow is initially distributed to the lowest elevation cell and then distributed proportioned by depth thereafter. There are no total inflows applied in the hydraulic model. Therefore, the routing is undertaken within the hydraulic model. The routing will be replicated in the WBNM hydrological model through a joint calibration process discussed in Section 5.

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

3.4.6 Tailwater Boundaries

A static tailwater of 0.76 mAHD at Donnybrook and 0.85 mAHD at Toorbul and Ningi has been adopted, noting this has not changed from the 2014 RFD modelling.

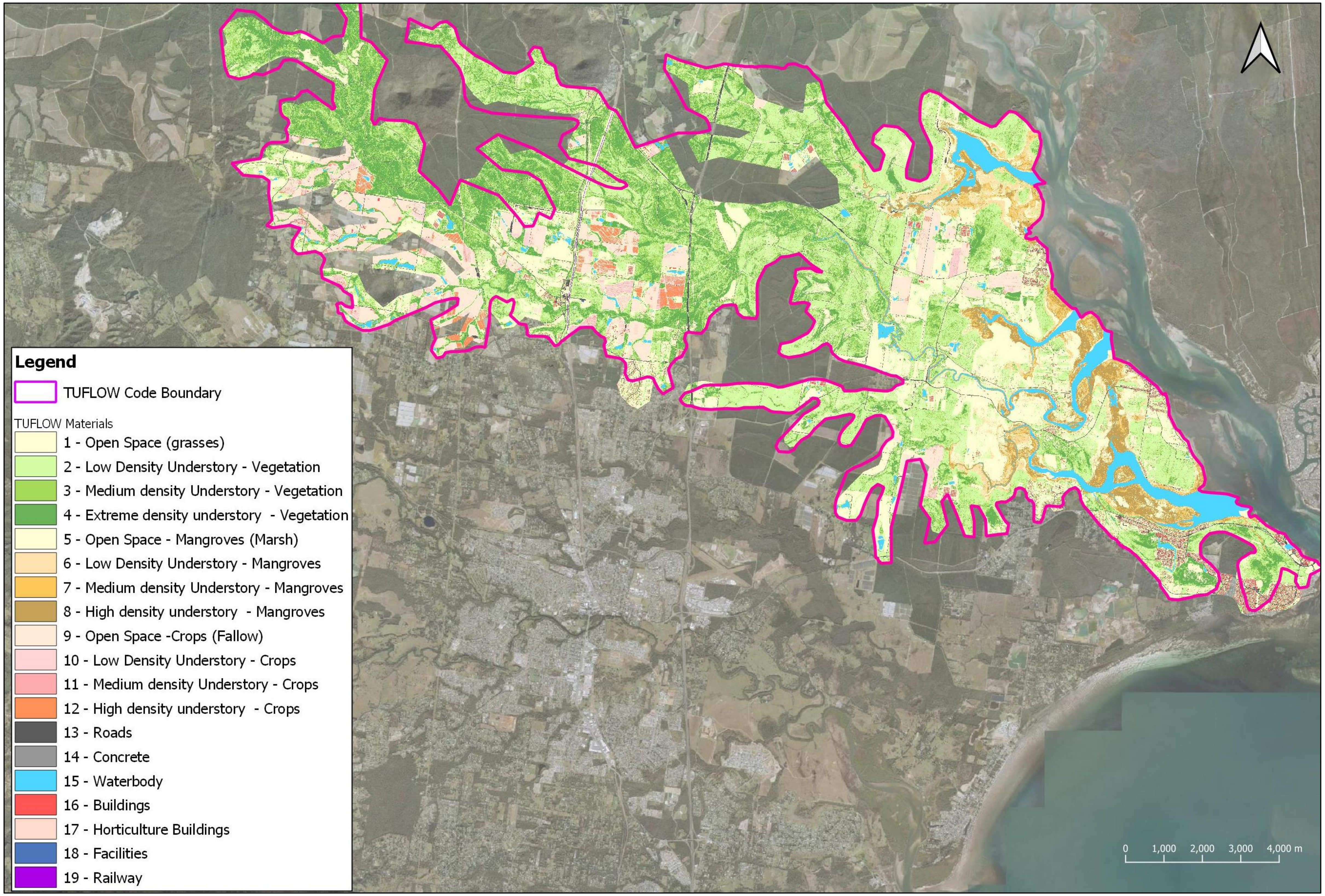

Figure 3-7 Hydraulic Model Roughness Layout

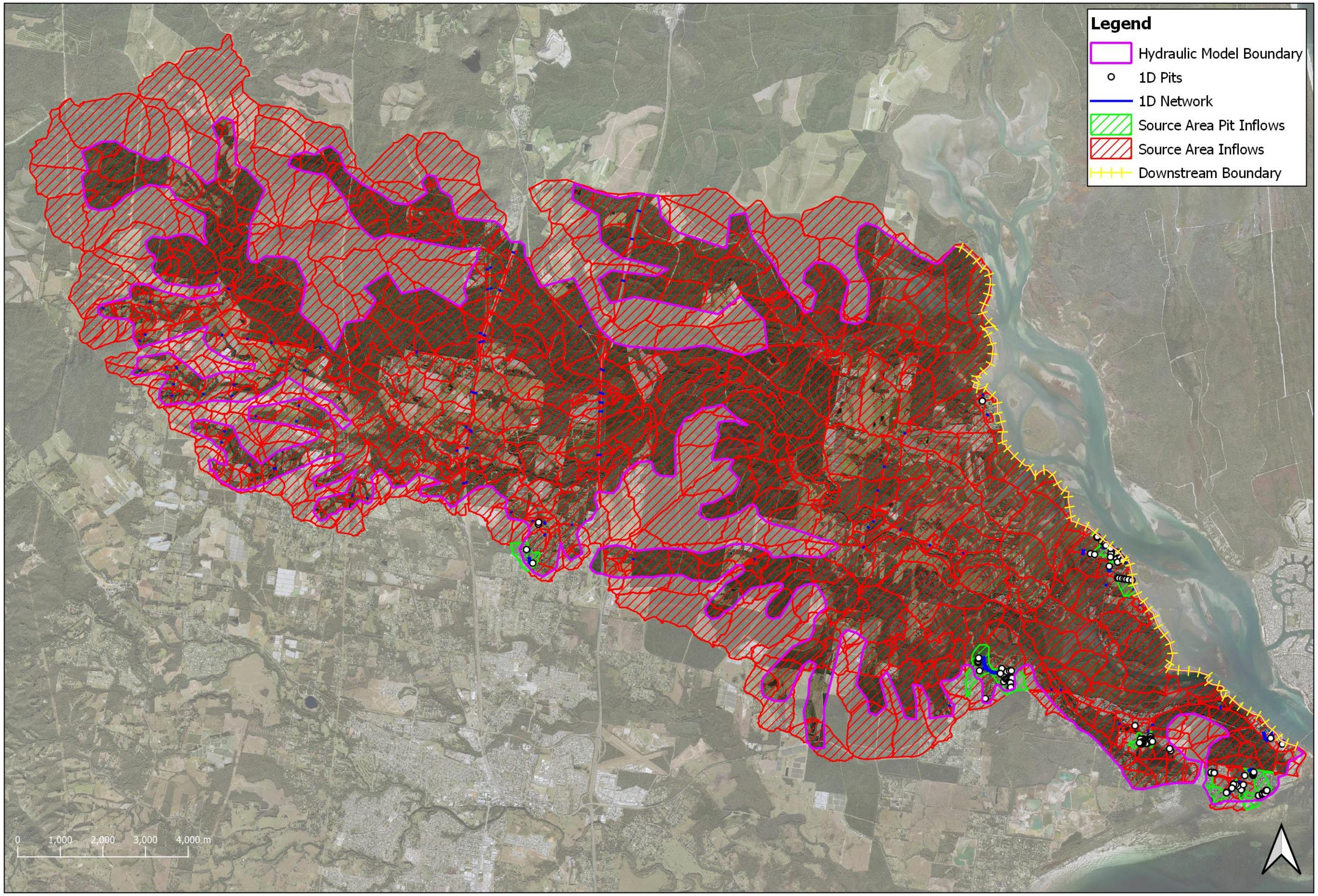

Figure 3-8 Hydraulic model trunk network and inflow boundaries

4 MODEL METHODOLOGY AND SIMULATIONS

4.1 Validation to Historical Events

Stream and rainfall gauge data for the Pumicestone study area was supplied by MBRC for use in this assessment. The location of these gauges, in relation to the PUM TUFLOW model extent, is presented in Figure 4-1. As evident from this figure, there is limited rainfall and stream gauging data within the study area. The following historical flood events were considered for the model validation:

- February 2015
- May 2015
- February 2022

4.1.1 Rainfall Data Available

MBRC supplied rainfall data at all rain gauge stations surrounding the respective catchments. Table 4-1 summarises the available data for the respective events and study catchments. Rainfall data was extracted for individual events by Council and was provided in CSV format.

Table 4-1 Rainfall Gauges Used for Validation

Gauge Name	ID	Event Availability
Elimbah (Rose Creek Rd) Alert	540543	April 2012 - Present
Toorbul (Donnybrook Rd) Alert	540635	December 2013 - Present
Wamuran (McClintock Rd) Alert	540652	October 2013 - Present
Elimbah (Eaton Rd) Alert	540653	October 2013 - Present

4.1.2 Stream Guage Data Available

There are two (2) stream gauges located within the Pumicestone study area, the details of which are outlined in Table 4-2.

Table 4-2 Stream Gauges Used for Validation

Gauge Name	ID	Event Availability
Elimbah (Rose Creek Rd) Alert	540543	March 2012 - Present
Toorbul (Donnybrook Rd) Alert	540635	May 2013 - Present

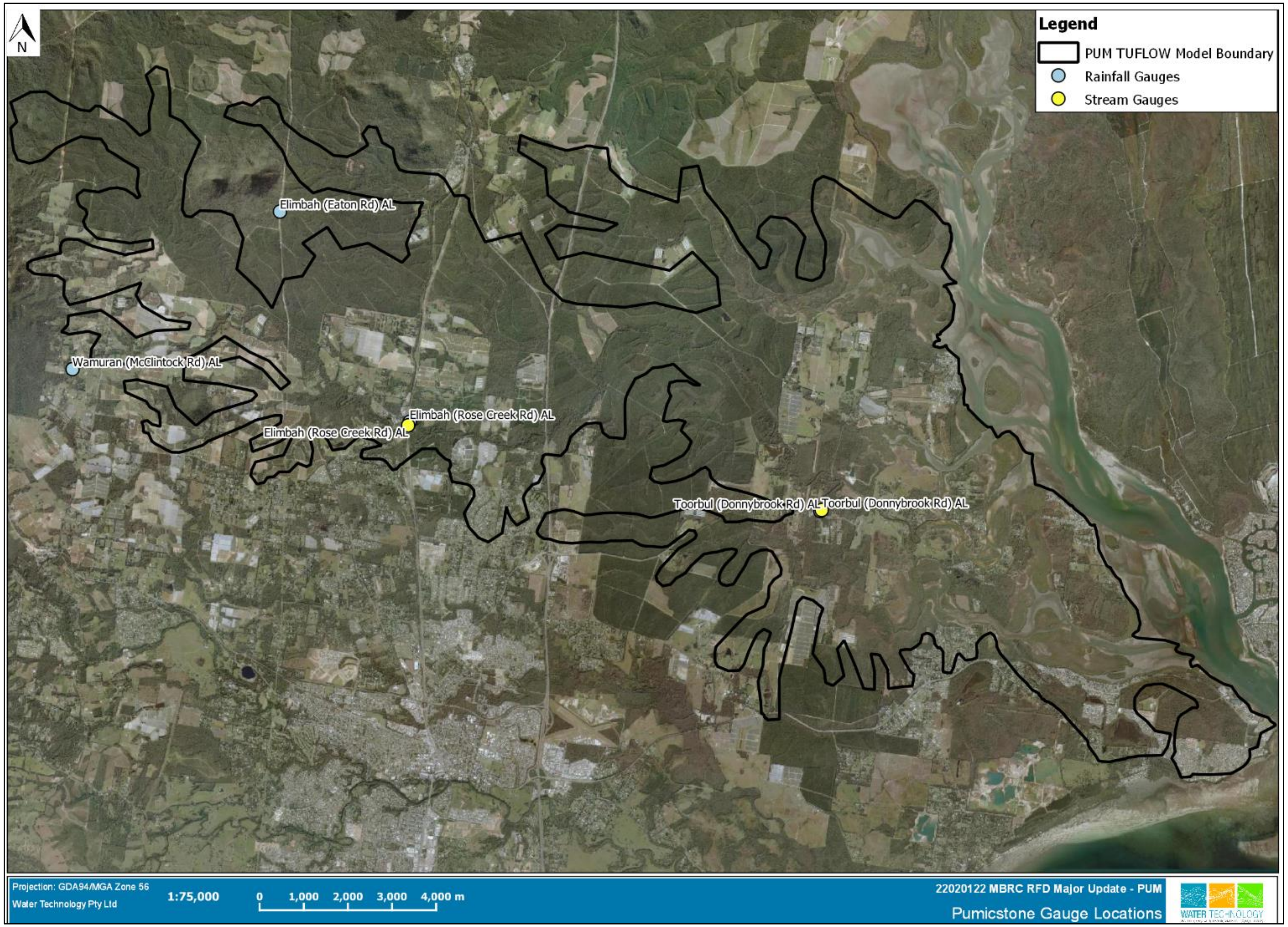

Figure 4-1 Rainfall and Stream Gauge Locations

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 respective historical events. It is noted that some debris marks were captured outside of the modelled flood extent and are most likely attributed to overland flow rather than the intent of the model which is flooding from creeks and waterways.

Table 4-3 Debris mark availability summary

Event	# of Debris Marks	# of Debris Marks in TUFLOW model extent
February 2015	8	7
May 2015	16	12
February 2022	96	81

4.1.4 Losses and Catchment Parameters

Table 4-4 presents the adopted Initial and Continuing Loss values for the validation event across the Pumicestone Passage 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

Event	Catchment Lag Parameter	Initial Loss (mm)	Continuing Loss (mm/hr)
February 2015	1.6	20	2.5
May 2015	1.6	20	2.5
2022	1.6	20	2.5

4.2 Hydraulic Equivalent Hydrologic (HEH) Model development

4.2.1 Points of Interest

Figure 4-2 presents the Points of Interest (POIs) adopted for the Pumicestone Passage catchment. There are 26 POIs in total across the catchment. The following comments are noted outlining the decision-making process applied in selecting these locations:

- The catchment includes two (2) known flood telemetry gauges Elimbah (Rose Creek Road Alert) and Toorbul (Donnybrook Road Alert stations), a significant number of known historical flood debris marks and numerous road closure locations.
- POIs have focused on the following locations (in order of priority):
  - Proximity to gauges and debris marks;

- At key infrastructure locations, including but not limited to QR alignments and the Bruce Highway;
- Proximity to known (MBRC supplied) Areas of Interests;
- At locations that would assist in obtaining a spread of Areal Reduction Factors (ARFs) throughout the catchment;
- Particularly unique catchments which showed significant storage upstream where the WBNM model will require refinement to represent critical durations; and
- At locations where future hydraulic model truncation can be undertaken with a minimum of fuss.

- The POIs have been assigned a purpose accordingly:
  - HEH: A point of interest that will be used to develop the Hydraulically Equivalent Hydrologic models
  - LOI: A Location of Interest (LOI) where intelligence or operational needs may dictate a requirement for future analysis of the modelling.

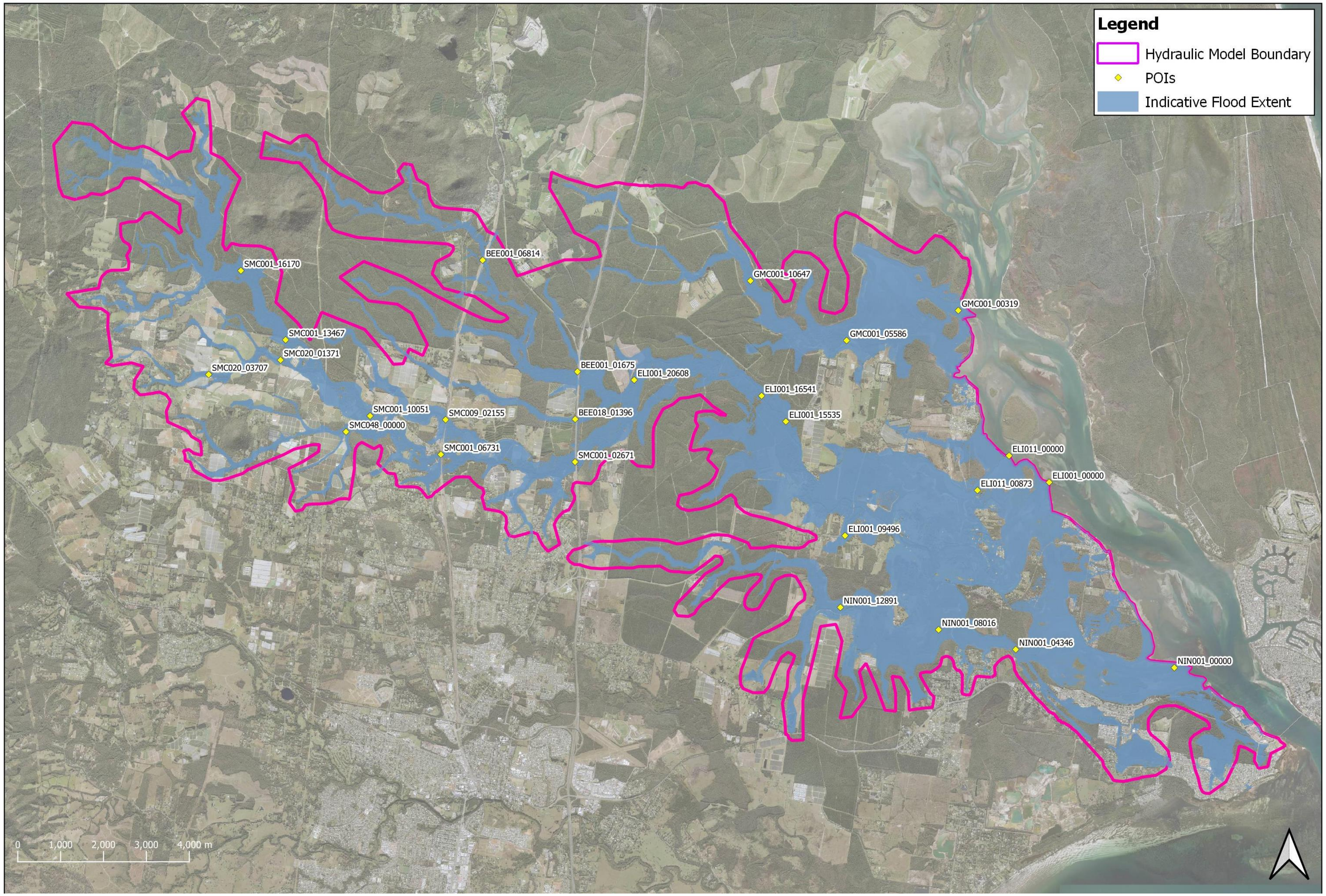

Figure 4-2 Point of Interest locations

4.2.2 Methodology

The methodology adopted to develop the HEH model for the Pumicestone Passage catchment has been based on the technical note provided by BMT titled "Final HEH Modelling Methodology" dated 22 August 2022 (see Appendix D). The results of the HEH assessment are presented graphically in Appendix C. A summary of the modelling process undertaken for the Pumicestone Passage catchment is provided below:

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

It is important to note that the HEH methodology was developed considering large floodplains and natural waterway systems which follow simplified one directional routing principals. The Pumicestone catchment is unique in that, upstream of the Bruce Highway, the catchment is appropriate for HEH modelling typified by channelised flows in clearly defined watercourses. Flooding behaviour downstream of the Bruce Highway is dominated by tailwater influences and generally widespread with significant interaction between flowpaths i.e. breakout flowpaths across streams. As such, achieving a good relationship with the WBNM and TUFLOW models downstream of the Bruce Highway has been challenging.

4.3 TUFLOW Hydraulic Model

4.3.1 Adopted Design Tailwater Conditions

A static tailwater of 0.76 mAHD at Donnybrook and 0.85 mAHD at Toorbul and Ningi has been adopted. 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 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 Pumicestone Passage 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 (19.7%), ultimate landuse and increased tailwater levels (+0.8m). The same storms selected for the current climate were modelled for future climate scenarios.

5 MODEL RESULTS AND OUTCOMES

5.1 TUFLOW Hydraulic Model Validation

5.1.1 February 2015

Figure 5-1 presents a spatial map of the hydraulic model validation results when comparing the TUFLOW model results to the surveyed flood depths for the February 2015 flood event.

Figure 5-2 and Figure 5-3 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the February 2015 flood event. As confirmed by MBRC, the water level data record for this event at the Elimbah (Rose Creek Road) Alert gauge appears to be flawed and incomplete as shown in Figure 5-2. As such, this dataset cannot be utilised for the validation of the February 2015 model at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-3, provides a better relationship with a peak modelled level of 3.66 mAHD compared to a recorded height of 3.45 mAHD.

The February 2015 event has limited data with only 7 marks to compare however 5 of the marks were within 200 mm difference compared to the recorded levels. As such, the hydraulic model has performed reasonably well in matching the observed flood marks for the February 2015 flood event.

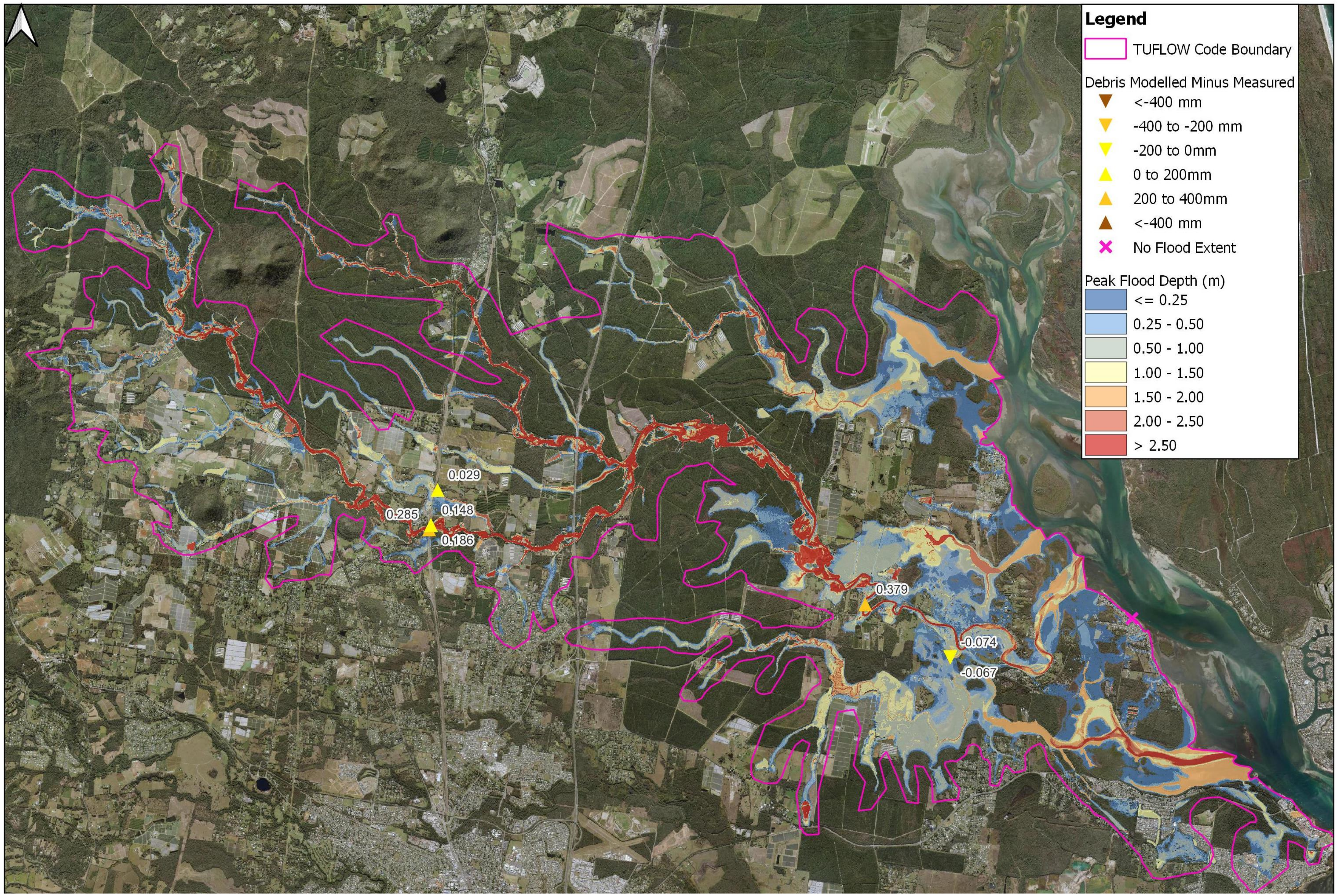

Figure 5-1 Pumicestone Passage February 2015 – extent and debris locations

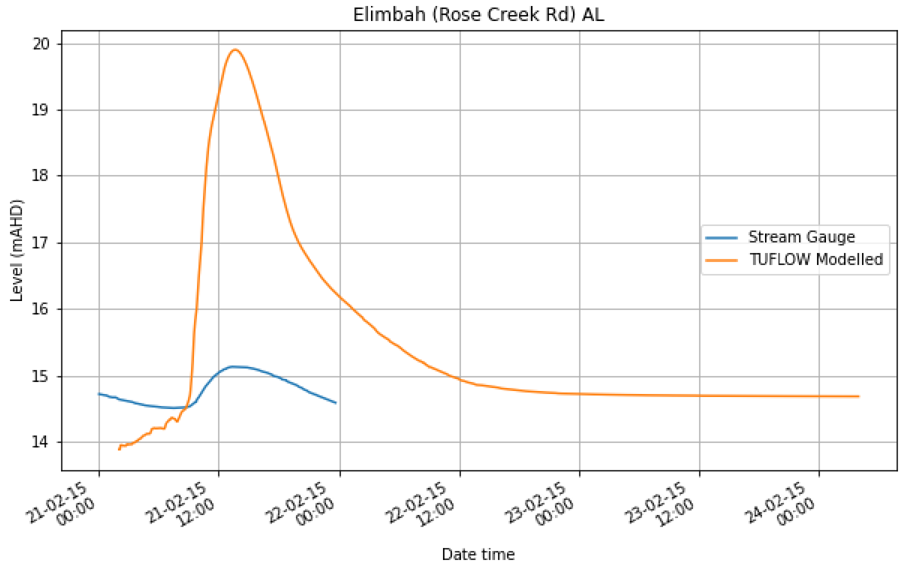

Figure 5-2 February 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

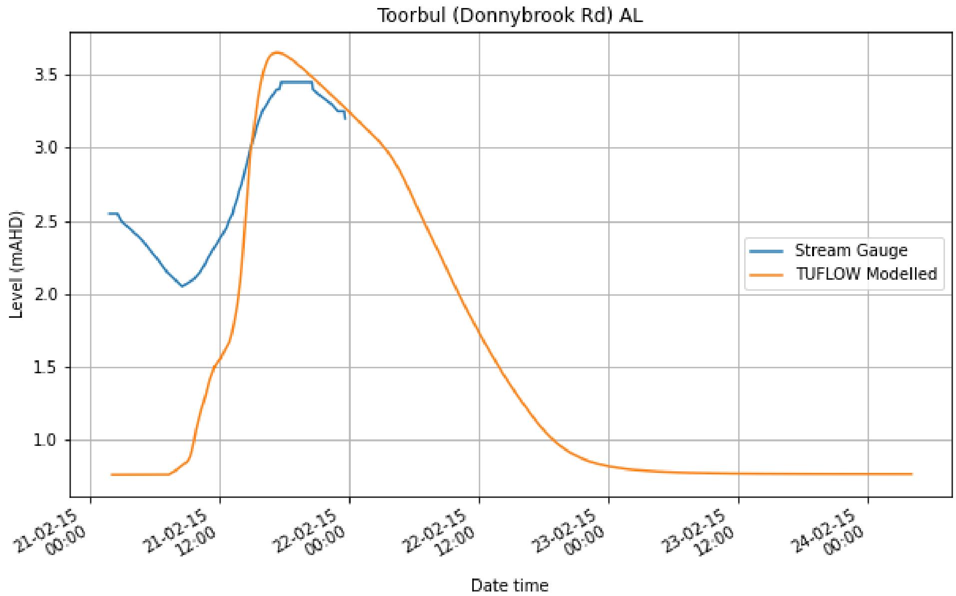

Figure 5-3 February 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

5.1.2 May 2015

Figure 5-4 presents a spatial map of the hydraulic model validation results when comparing the TUFLOW model results to the surveyed flood depths for the May 2015 flood event. The May 2015 event was found to be more severe than the February 2015 event.

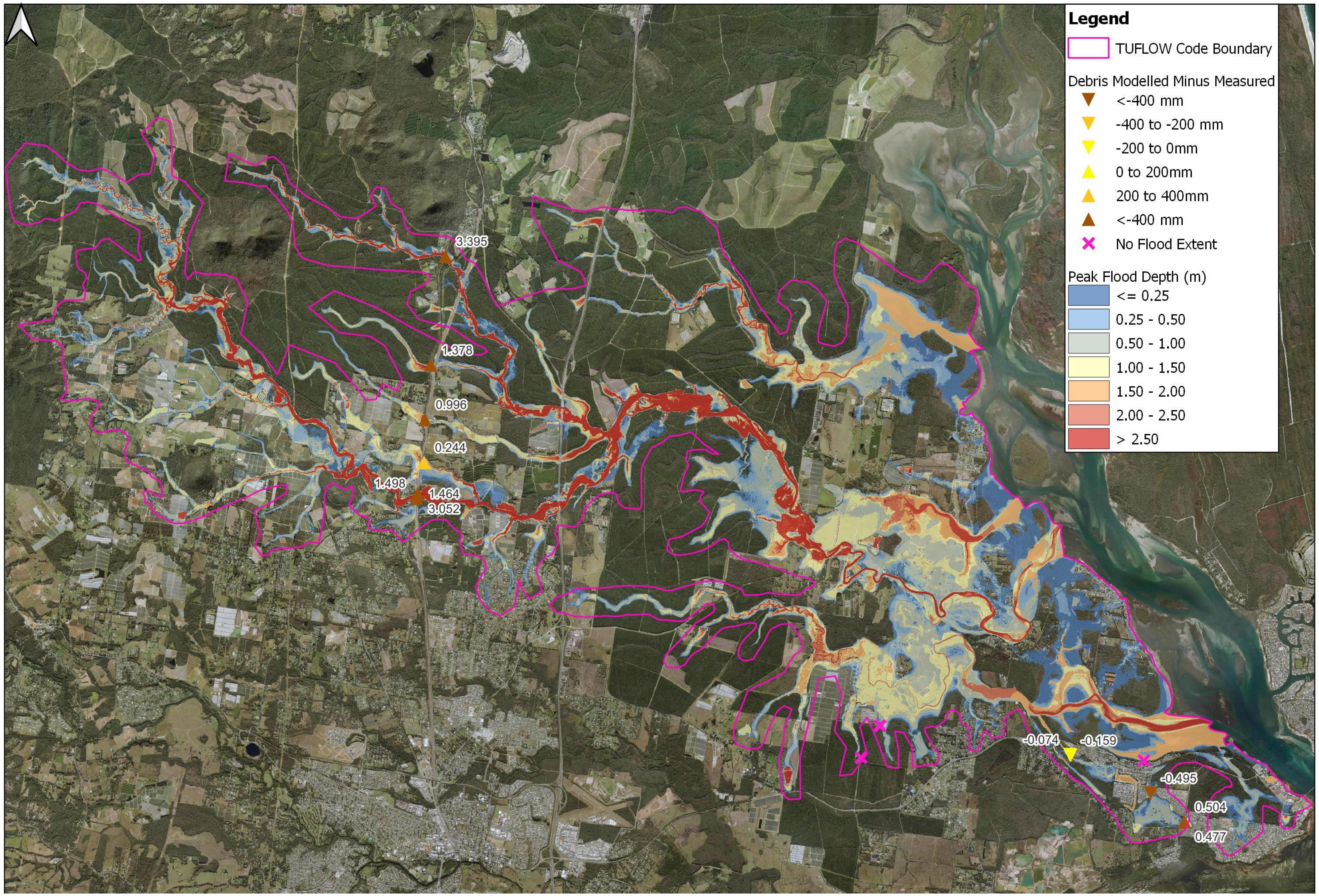

Figure 5-4 Pumicestone Passage May 2015 – extent and debris locations

Figure 5-5 and Figure 5-6 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the May 2015 flood event. As confirmed by MBRC, the water level data record for this event at the Elimbah (Rose Creek Road) Alert gauge appears to be flawed and incomplete as shown in Figure 5-5. As such, this dataset cannot be utilised for the validation of the May 2015 model at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-6 provides a better relationship with a peak modelled level of 4.075 mAHD compared to a recorded height of 3.70 mAHD.

Appendix A provides the histogram distribution of the differences between measured and modelled water levels. The May 2015 event has limited data with only 12 marks to compare. It is noted that there does not appear to be a good relationship between the measured debris heights and the modelled peak water levels. Debris marks where the comparison was less than 200 mm occurred in isolated reaches of the system which

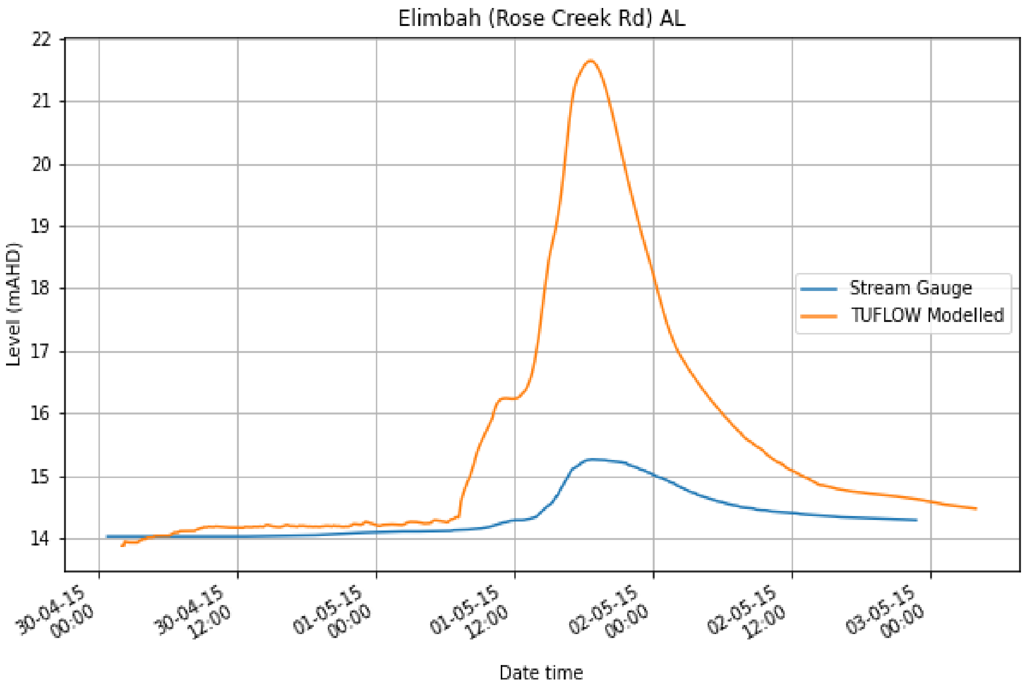

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Figure 5-5 May 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

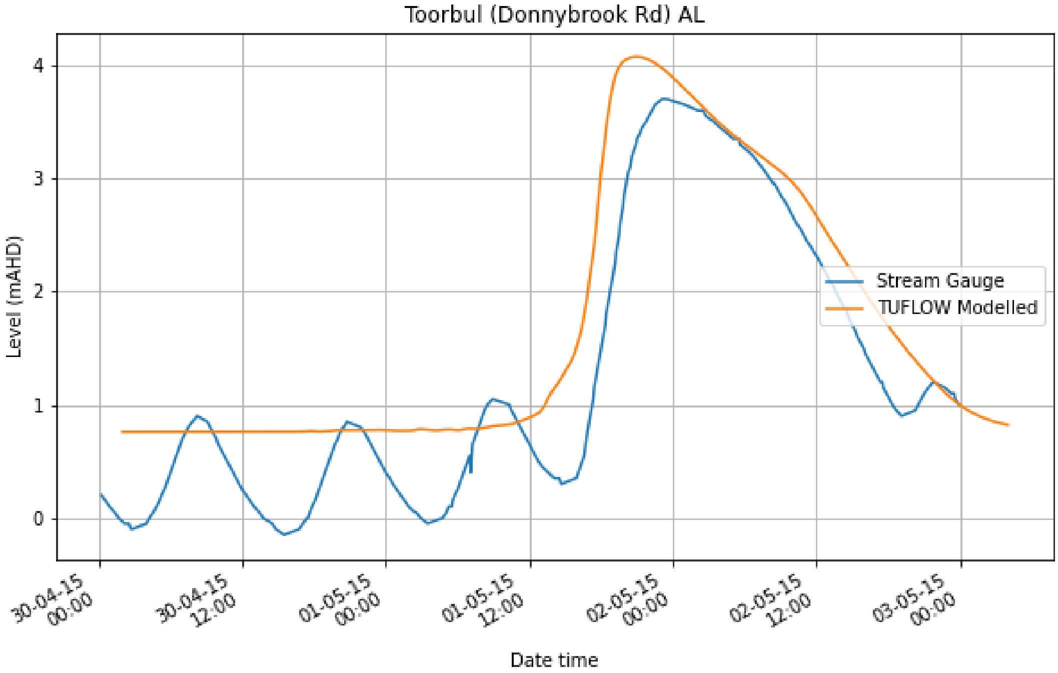

Figure 5-6 May 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

5.1.3 February 2022

Figure 5-7 presents a spatial map of the hydraulic model validation results when comparing the TUFLOW model results to the surveyed flood depths for the February 2022 flood event.

Figure 5-8 and Figure 5-9 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the February 2022 flood event. Recorded rainfall has also been included in these plots to better illustrate the reaction of the catchment to rainfall. As shown in Figure 5-8, the modelled water levels provide a good comparison to the recorded water level at the Elimbah (Rose Creek Road) Alert gauge with a peak modelled level of 22.082 mAHD compared to a recorded height of 21.79 mAHD. The timing and shape of the modelled water level hydrograph confirms that an excellent representation of the February 2022 event has been replicated at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-9 provides a similar result with a peak modelled level of 3.95 mAHD compared to a recorded height of 4.20 mAHD.

Appendix A provides the histogram distribution of the differences between measured and modelled water levels. There is extensive debris mark data for the February 2022 flood event and the modelled levels compare well. Of the 81 debris marks analysed, 34 marks (42%) have a modelled level of +/- 200mm when compared to the recorded heights. 21 marks (26%) have a comparison of +/- 100mm when compared to the recorded heights. As such, the TUFLOW model for the February 2022 flood event provides an exceptional representation of the February 2022 historical flood event.

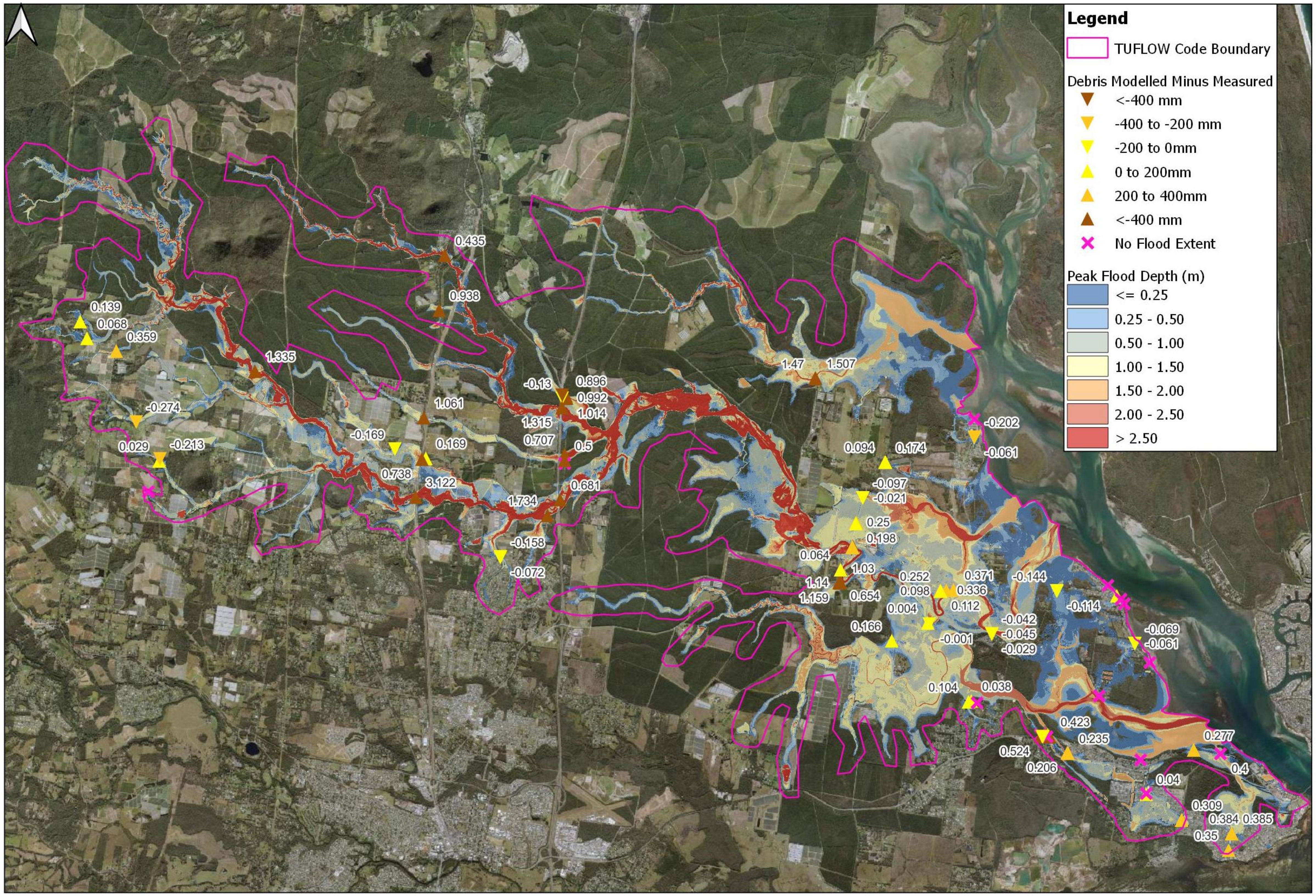

Figure 5-7 Pumicestone Passage February 2022 – extent and debris locations

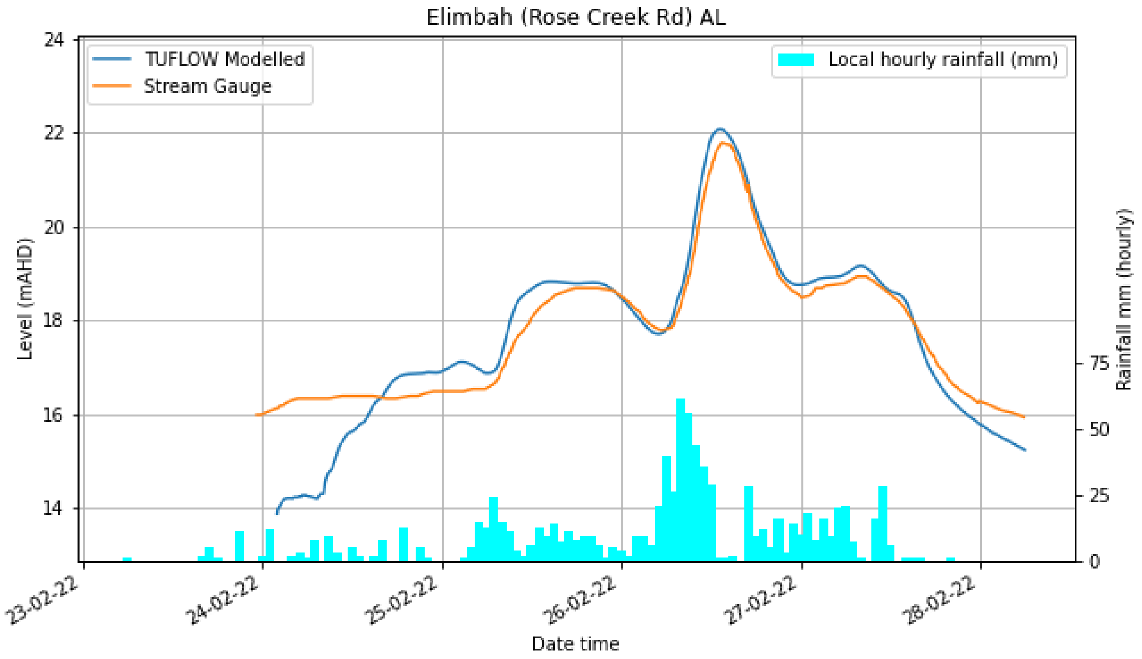

Figure 5-8 February 2022 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

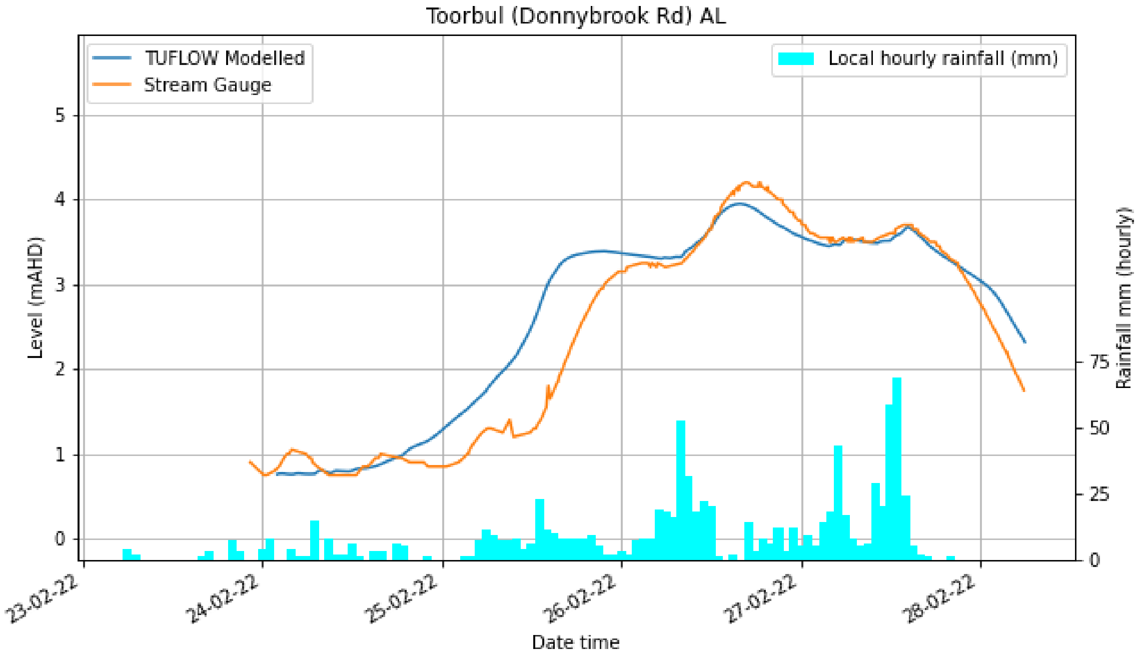

Figure 5-9 February 2022 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

5.1.4 Summary

The validation methodology and results provided within this report has improved the confidence of the modelling outputs throughout the Pumicestone Passage catchment. Specifically, through comparison of modelled peak levels and measured debris marks there is increased confidence in both the hydrologic and hydraulic model parameters adopted. Considering the uncertainty of the hydrologic modelling with limited stream gauge calibration, these results are encouraging and suggest the adoption of the parameters for the hydrologic and hydraulic model is valid. The interim memorandum prepared by Water Technology and supplied to Council is presented in Appendix E.

5.2 WBNM Hydraulic Equivalent Hydrologic Model performance

Appendix C provides a tabular description of the plots and statistic tables for each simulated event/duration at each POI. The HEH modelling was undertaken to add confidence that the Pumicestone Passage WBNM model is representing the catchments hydraulic response (where possible) through alteration of stream routing parameters and the addition of artificial storage curves. 10 of the 26 POI locations required artificial storage curves added into the WBNM model. This was undertaken to assist with the design storm selection based on advice outlined in the Stage 1 Pilot Study.

Only three (3) locations met the HEH criteria for all modelled events. Despite this, most comparison of hydrographs have NSE values over 0.9 with the shape and peaks being replicated well, particularly upstream of the Bruce Highway. Generally, the criteria which was unable to be met was the peak timing being within 15 minutes for all events and durations. For the locations where representative hydrograph matches were unable to be made (mainly in lower parts of the catchment), 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 given the challenges of the catchment, the Pumicestone Passage HEH model is suitable to inform design event storm selection with additional hydraulic model simulations to account for the uncertainties documented herein.

5.2.1 Critical Storm Selection

Table 5-1 presents the selected storm events simulated in the TUFLOW model. Following on from Stage 1 guidance the following process was undertaken for the design event selection. The storms were selected using the HEH model and the process was undertaken for each ARF category (within Storm Injector software) described in Section 3.3.4.

1. Design storms generated with relevant ARF applied.
2. Storms with embedded bursts where smoothing over 40% were removed from the analysis.
3. WBNM HEH model simulated for all design storms.
4. Critical storms and peak flows extracted for corresponding POIs for each ARF category (refer to Section 3.3.4).

From this analysis there was approximately 15 storms critical across the POIs from the WBNM modelling for each AEP. To reduce the number of hydraulic simulations, a process was undertaken to optimise the selected storms for hydraulic simulation. This process involved comparing the WBNM HEH peak flow from a subset of 5 storms (4 storms for the 0.1% and 0.05% AEPs) to the actual critical peak flow (from all storms) across all POIs. All possible combinations of critical storms were tested, and the optimal subset of storms was selected for each AEP based on the mean and minimisation of outlier flow differences. In general, this over or underestimation was aimed to be under +-10%. Table 5-2 presents the difference in peak flow (HEH WBNM modelling) from the maximum of the selected events versus the peak flow from simulating all temporal patterns and durations showing that differences are generally less than 10%.

Table 5-1 Critical Events Selected

Event	Simulated events
20%	180minTP01_ARFb, 270minTP09_ARFc, 360minTP3_ARFe, 1080minTP01_ARFf
10%	180minTP04_ARFc, 360minTP07_ARFe, 540minTP09_ARFe, 1080minTP01_ARFf, 720minTP3_ARFf
5%	180minTP08_ARFc, 360minTP10_ARFe, 540minTP7_ARFe, 1080minTP10_ARFf, 720minTP03_ARFf
2%	120minTP08_ARFb, 270minTP02_ARFd, 360minTP09 ARFe, 720minTP01_ARFf, 720minTP05_ARFf
1%	120minTP08_ARFb, 270minTP07_ARFd, 360minTP10 ARFe, 1080minTP01_ARFf, 720minTP05_ARFf
1 in 1000	120minTP08_ARFc, 270minTP09_ARFc, 360minTP10_ARFe, 1440minTP09_ARFf, 720minTP03_ARFf
1 in 2000	120minTP08_ARFc, 270minTP02_ARFd, 360minTP09_ARFe, 1440minTP09_ARFf, 720minTP01_ARFf

Table 5-2 Peak Flow Over/Underestimation at POIs

POI	Peak Flow Difference with Selected Storms (% difference to all storms critical flow)		
	5% AEP	1% AEP	0.01% AEP
BEE001_01675	-3%	0%	-2%
BEE001_06814	5%	1%	-7%
BEE018_01396	0%	-3%	2%
BEE018_01396	0%	0%	6%
ELI001_00000	0%	-1%	0%
ELI001_09496	0%	-1%	0%
ELI001_15535	8%	13%	8%
ELI001_16541	8%	14%	8%
ELI001_20608	11%	14%	11%
ELI011_00000	0%	-3%	-3%
ELI011_00000	5%	0%	2%
ELI011_00873	-1%	-2%	0%
ELI011_00873	1%	2%	5%
GMC001_00319	0%	0%	1%
GMC001_10647	0%	-3%	-6%
GMC001_10647	4%	0%	-2%
NIN001_00000	0%	0%	0%
SMC001_02671	-1%	-2%	-4%
SMC001_06731	-1%	-2%	0%

SMC001_10051	-3%	3%	2%
SMC009_02155	0%	-3%	-4%
SMC009_02155	4%	0%	0%
SMC020_01371	1%	2%	0%
SMC020_01371	5%	5%	6%
SMC020_03707	-5%	0%	-10%
SMC034_00000	0%	-3%	-7%
SMC034_00000	5%	1%	-3%

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 5-3 presents the comparison for the 1% AEP event (E00). The results show reasonable correlation between the models with similar peak flows and similar critical storms giving further confidence that the HEH WBNM is suitable to be utilised for the selection of critical storms.

Table 5-3 1% AEP WBNM vs TUFLOW Peak Flow Comparison

POI	WBNM Duration (min)	WBNM Adopted TP	WBNM Peak flow	TUFLOW Duration (min)	TUFLOW Adopted TP	TUFLOW Peak flow
SMC020_03707	120	TP08	537.1	120	TP08	463.8
GMC001_10647	270	TP07	447.9	270	TP07	465.4
GMC001_10647	270	TP07	475.8	270	TP07	474.1
SMC009_02155	270	TP07	467.1	360	TP10	475.4
SMC009_02155	270	TP07	466.3	360	TP10	476.9
SMC034_00000	270	TP02	362.1	120	TP08	320.7
SMC034_00000	270	TP02	292.4	120	TP08	267.7
SMC020_01371	270	TP08	269.9	120	TP08	274.5
SMC020_01371	270	TP08	238.9	120	TP08	267.6
BEE018_01396	270	TP07	177.4	270	TP07	192.7
BEE018_01396	270	TP07	138.7	270	TP07	137.9
ELI011_00000	270	TP07	92.5	120	TP08	90.2
ELI011_00000	270	TP07	141.0	120	TP08	165.3
ELI011_00873	270	TP09	44.9	120	TP08	45.3
ELI011_00873	270	TP09	19.9	120	TP08	18.7
BEE001_06814	270	TP08	98.7	270	TP07	97.0
BEE001_01675	270	TP07	104.6	270	TP07	122.6
NIN001_00000	360	TP07	77.4	360	TP10	87.9

POI	WBNM Duration (min)	WBNM Adopted TP	WBNM Peak flow	TUFLOW Duration (min)	TUFLOW Adopted TP	TUFLOW Peak flow
GMC001_00319	360	TP10	30.0	360	TP10	29.1
SMC001_10051	360	TP03	25.3	270	TP07	23.9
SMC001_06731	360	TP03	14.0	360	TP10	15.0
SMC001_02671	360	TP07	47.1	360	TP10	42.8
ELI001_20608	720	TP03	1454.5	360	TP10	1640.7
ELI001_16541	720	TP05	11.4	360	TP10	8.8
ELI001_15535	720	TP05	1530.3	360	TP10	1540.6
ELI001_09496	720	TP10	1522.1	120	TP08	1545.0
ELI001_00000	720	TP10	976.5	120	TP08	1015.0

The validation methodology and results provided within this report has improved the confidence of the modelling outputs throughout the Pumicestone Passage catchment. Specifically, through comparison of modelled peak levels and measured debris marks there is increased confidence in both the hydrologic and hydraulic model parameters adopted. Considering the uncertainty of the hydrologic modelling with limited stream gauge calibration, these results are encouraging and suggest the adoption of the parameters for the hydrologic and hydraulic model is valid.

5.3.2 Comparison to RFD 2014

Figure 5-10 presents the difference in 1% AEP peak flood level between the RFD 2022 (E00 1% AEP of this study) and the previous RFD 2014 peak flood level across the Pumicestone Passage catchment (unblocked scenarios). It is noted that RFD 2014 did not incorporate blockage into the catchment. In general, the peak flood levels are higher across the catchment, particularly in the upper reaches of Six Mile Creek upstream of the Bruce Highway where the flood extent has significantly increased. This is partially attributable to increased riparian roughness where previously no riparian roughness was defined and augmentation of the RFD model to include minor tributaries in the upper catchment areas. Similarly, water levels and the extent of inundation has increased in Elimbah Creek downstream of the Bruce Highway. It should also be noted that the 2014 RFD model did not include the extensive works associated with the upgrade of the Bruce Highway in this section of the catchment.

There are no notable sections of the model whereby a reduction in the 1% AEP peak flood level has occurred. Some slight reductions occur in the upper reaches of Glass Mountain Creek but these increases are isolated to one arm of the waterway.

A similar comparison has been undertaken for the Defined Flood Event (DFE) which for this major update is the enveloped future climate 1% AEP scenario (F03 blocked and unblocked). Figure 5-11 presents a comparison of flood levels of the 2022 RFD DFE to the RFD 2014 DFE which was based of the Moreton Bay Design Storm (MDS). Similar increases and decreases as discussed above are notable.

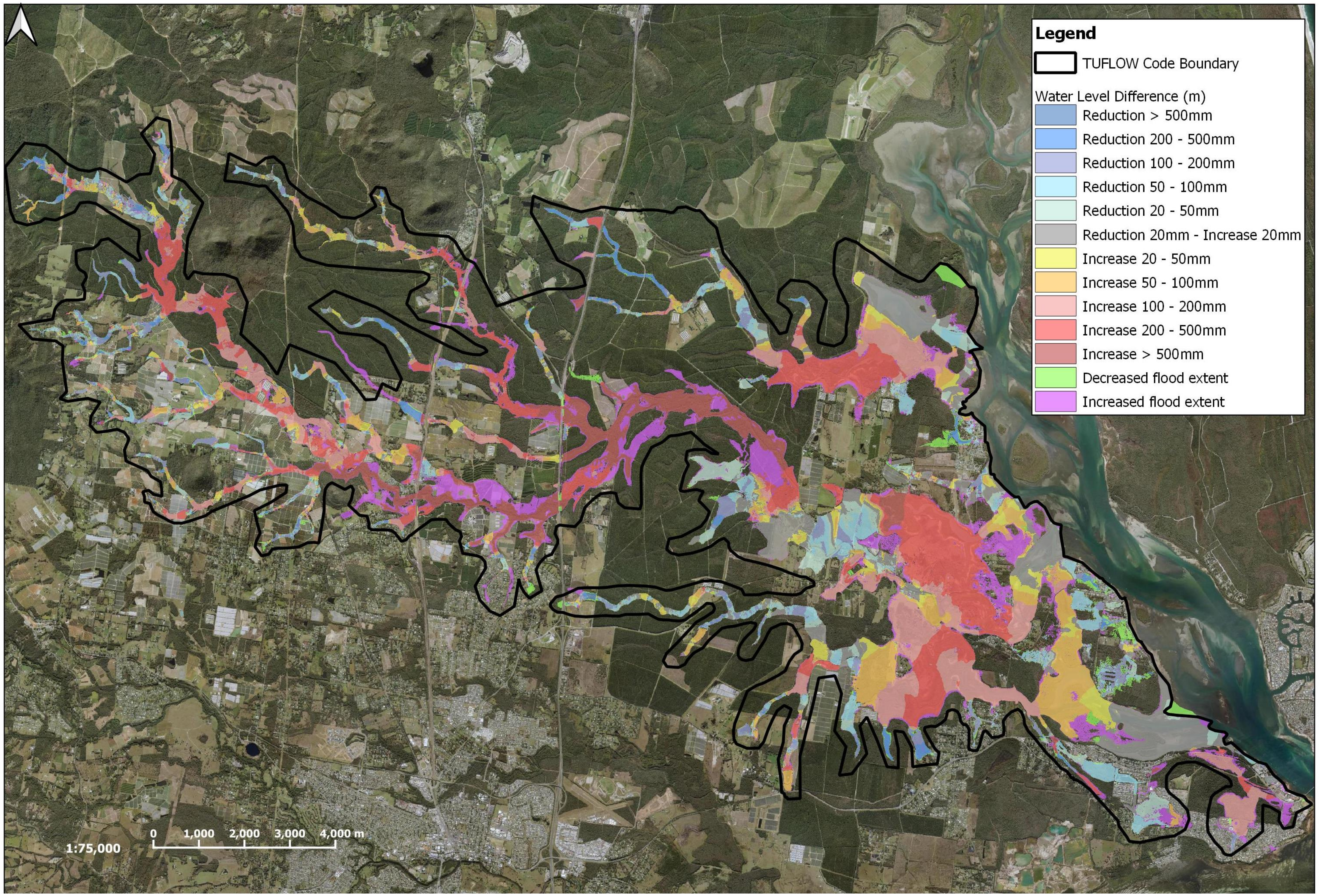

Figure 5-10 RFD 2022 minus RFD 2014 1% AEP peak flood level (unblocked)

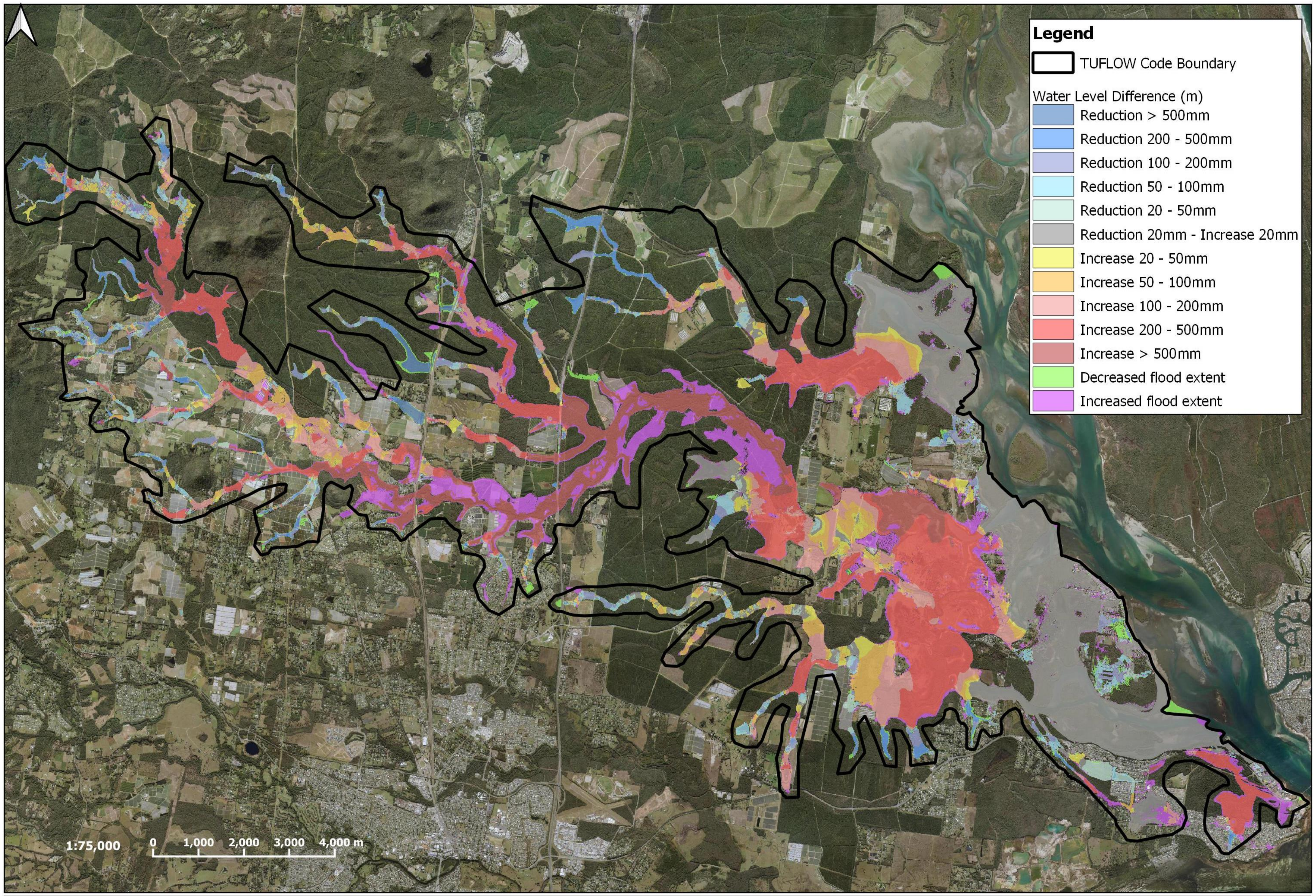

Figure 5-11 RFD 2022 minus RFD 2014 1% AEP DFE peak flood level (future climate)

5.4 Model Limitations and Quality

A plot showing the control numbers and minimum timestep (dt) during the 1% AEP 360-minute event (E02) is shown in Figure 5-12. The minimum dt value dips below 0.2 seconds in most simulations and is associated with deep, fast-moving water as the event peaks. Mapping for the minimum dt shows that cells dictating the timestep are isolated to incised channels and deep downstream channels of the model, which is to be expected. The pattern and response of the control numbers and timestep is normal for a model of this extent, grid size and complexity.

HPC is mass-conserving, so the low Mass Error (ME) is expected, however, the low ME values indicate that the 1D elements and connections are generally stable. Inspections of the culvert flows indicate that pits, pipes and major culverts are stable and performing as intended.

Watercourses within the Pumicestone catchment were represented using a fixed 2D grid size of 5m. This may not allow adequate representation of minor drainage channels, particularly roadside or urban drains and particularly for smaller, more frequent flood events.

The model terrain is based on available 2019 LiDAR. Substantial effort was made to include recent developments and any other catchment changes in the model (such as new roads and bridges). However, there are likely to be areas of the model that do not represent current conditions.

The adopted model roughness was based on previous work undertaken by others in the Stage 2 study and endorsed by Council. Spatially, the materials layers are highly refined and represent a substantial improvement from the previous RFD modelling.

Predicted water levels are dependent on the event selection process as documented herein. Analysis of the WBNM HEH model has shown that for the 1% AEP, the difference between the peak flow of the selected storm and median at each POI is generally less than 10%. Similar results were attained for the 5% and 0.1% AEP events. The ensemble results are therefore adequate for design event representation and to inform future planning.

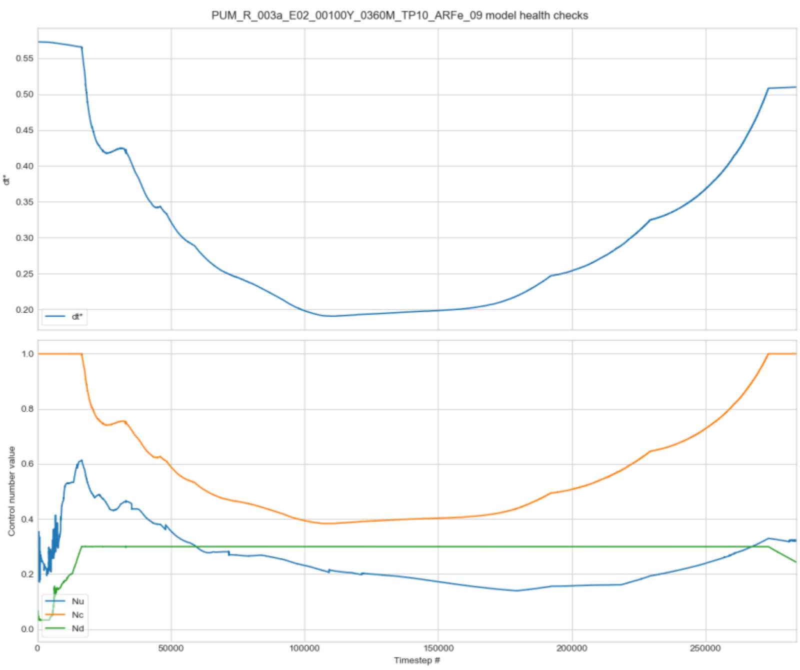

Figure 5-12 TUFLOW Control Numbers and Timestep

5.5 Model Specification and Run Times

Pumicestone is one of the larger catchments within the MBRC RFD study area, encompassing 170.3 km^2 and 23,034,700 grid cells (at 5m cell size). Table 5-4 provides a summary of the Pumicestone Passage TUFLOW model specification and run times. It is noted that runtimes will vary depending on CPU and GPU hardware used.

Table 5-4 Pumicestone Passage model specification and run times

Event	Model run time (hours) (varies per duration)	Startup Memory (MB)	GPU memory required (MB)
20% AEP (360min)	6	8400	4227
1% AEP (360min)	6.75		
1 in 2000 AEP (360min)	7.5		

6 CONCLUSION

As part of the Stage 4 and 5 update of the RFD for Pumicestone Passage, a provided WBNM hydrologic (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 Floodplain 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 Pumicestone Passage 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 Pumicestone Passage 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 and 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 Pumicestone Passage 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 Pumicestone Passage catchment representing a significant improvement over previous iterations.

It is important to note that the models have been validated to two (2) stream gauges and to historical debris marks which have significant uncertainty. Additional stream gauge within the Pumicestone Passage 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 additional stream gauges would give further confidence in model parameterisation and the resulting design flood level outputs.

8 REFERENCES

1. Australian Rainfall and Runoff (ARR) (2019): A guide to flood estimation, Commonwealth of Australia (Geoscience Australia), 2016.
2. Bureau of Meteorology: Design Rainfall Data System (2016) available at: http://www.bom.gov.au/water/designRainfalls/revised-ifd/
3. Memorandum - Final HEH Modelling Methodology, BMT, 2022
4. Moreton Bay Regional Council Regional Flood Database ARR 2019 Pilot Study Part 1 Methodology Report & Part 2 Pilot Study Report, ARUP, 2021
5. Regional Flood Database - Hydrologic and Hydraulic Modelling Report – Pumicestone Passage (PUM), Aurecon, 2012
6. Regional Flood Database - 2014 Model Maintenance Report – Pumicestone Passage (PUM), Water Technology, 2014
7. Regional Flood Database - Stage 2 - Hydrography Landuse and Hydrology, AECOM, 2020
8. Regional Flood Database – Stage 3 Analysis Summary, Moreton Bay Regional Council, 2021

APPENDIX A
POI ARF CLASSIFICATION

POI ID	Total Upstream Area (km^2)	ARF Class
SMC020_03707	2.8	A
SMC009_02155	5.1	A
BEE018_01396	5.5	A
SMC020_01371	6.8	A
ELI011_00873	7.6	A
ELI011_00000	8.1	A
SMC034_00000	10.4	A
GMC001_10647	13.5	A
BEE001_06814	15.7	A
NIN001_12891	17.9	A
GMC001_05586	23.0	B
NIN001_09018	26.6	B
BEE001_01675	27.4	B
SMC001_16170	28.8	B
SMC001_13467	32.2	B
NIN001_04346	32.3	B
GMC001_00319	35.7	C
SMC001_10051	41.6	C
NIN001_00000	43.6	C
SMC001_06731	54.2	C
SMC001_02671	68.4	C
ELI001_20608	111.5	D
ELI001_16541	117.1	D
ELI001_15535	118.2	D
ELI001_09496	130.5	D
ELI001_00000	137.7	D

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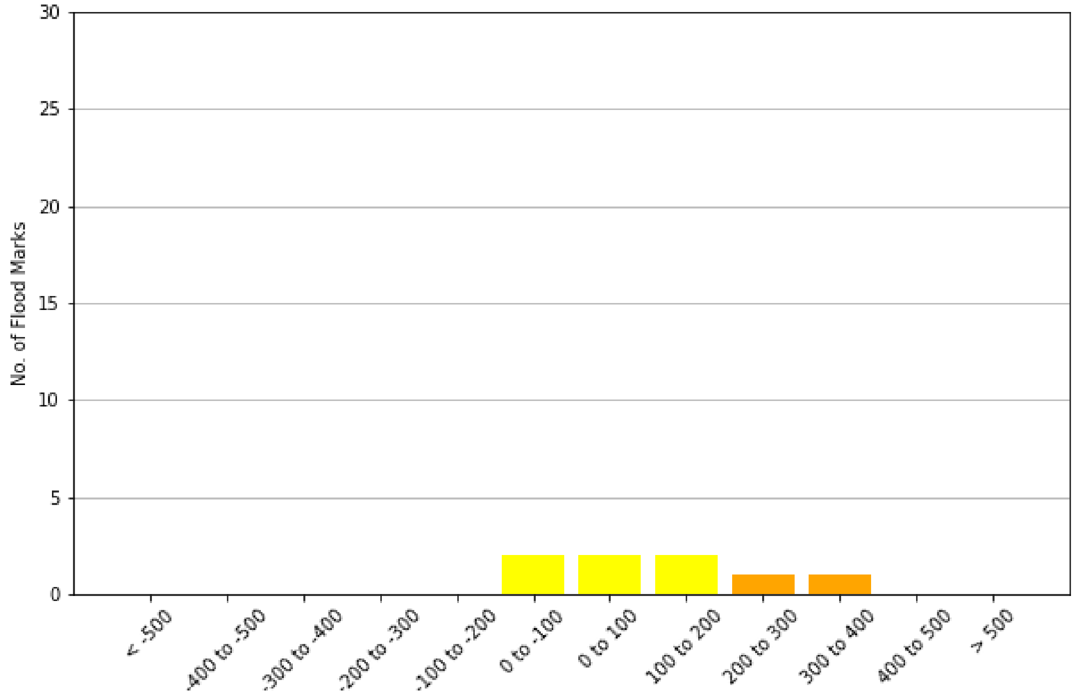
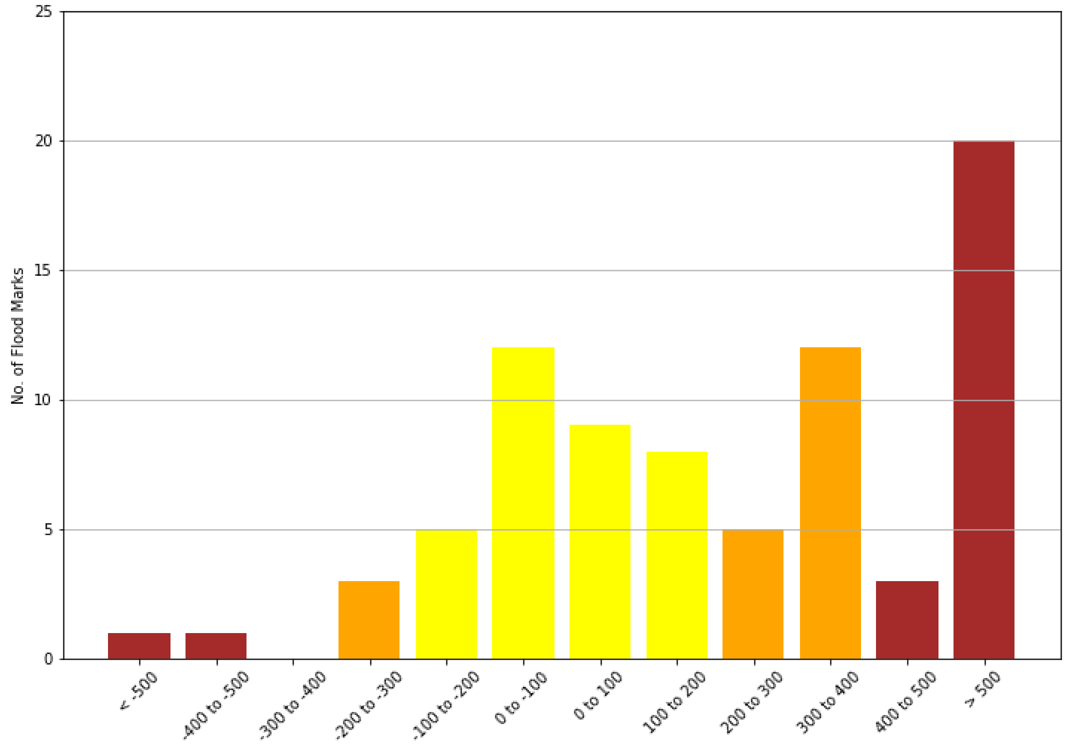
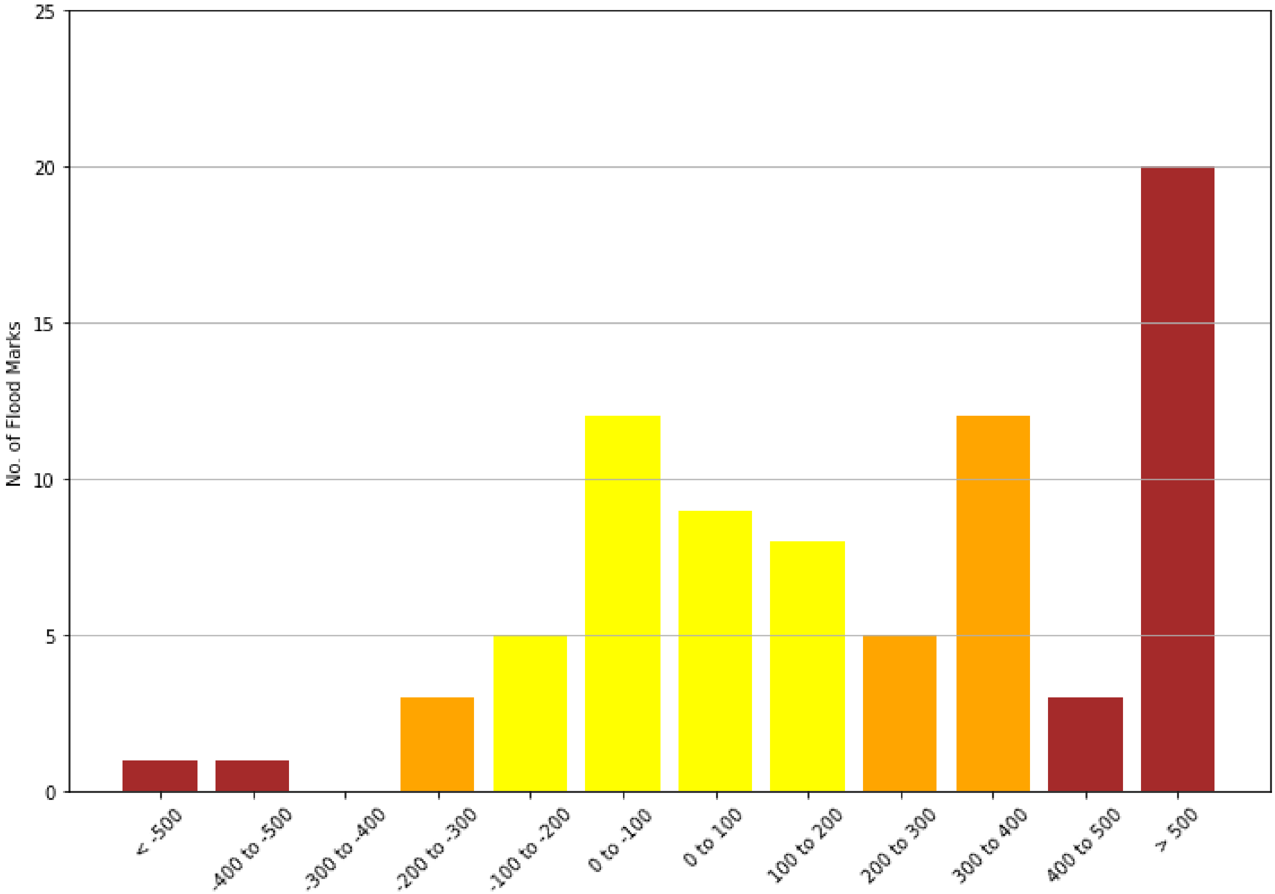
APPENDIX B
FLOOD MARK ANALYSIS



Difference in Water Level Modelled v Measured – February 2015



Difference in Water Level Modelled v Measured – May 2015



Difference in Water Level Modelled v Measured – February 2022

APPENDIX C
HEH PLOTS AND SUMMARY TABLES

Table 1 POI HEH performance summary

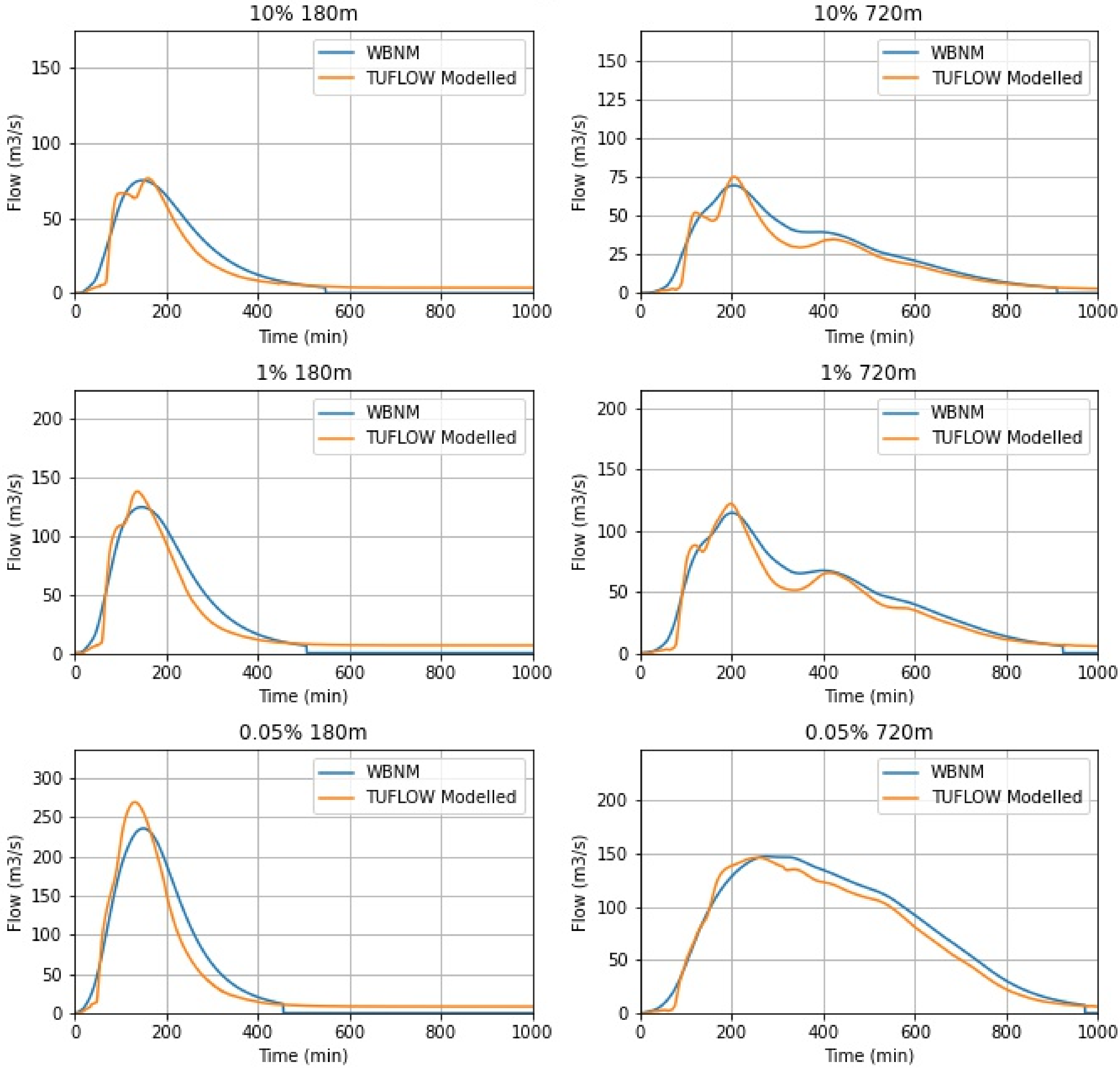
POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
SMC034_00000	✗		✗	4/6 events meet criteria. All NSE values over 0.9 with good match of shape.
SMC020_03707	✗		✓	
SMC020_01371	✗		✓	
SMC009_02155	✗		✗	Good match on peaks (4/6 within 10%). Unable to replicate rising limb and peak timing.
SMC001_16170	✓	Significant vegetation attenuating flows upstream of this location.	✗	Good match on peaks (all within 5%). Unable to replicate peak timing although all NSE over 0.97.
SMC001_13467	✓	Significant storage upstream of Twin View Road	✗	Good match on peaks (5/6 within 5%). Unable to replicate peak timing for 5/6 events although NSE all over 0.9.
SMC001_10051	✗		✗	Good match on peaks (5/6 within 5%). Unable to replicate peak timing for 5/6 events although NSE all over 0.89.
SMC001_06731	✗		✓	
SMC001_02671	✓	Flat terrain upstream of the Bruce Highway attenuating flows.	✗	Good match on peaks (all within 5%). Unable to replicate peak timing for 4/6 events although all NSE over 0.9.

POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
BEE018_01396	✘		✘	Good match on peaks (3/6 within 10%). Unable to replicate rising limb and peak timing although all NSE over 0.9
BEE001_06814	✘		✘	Good match on peaks (all within 7%). Good match for 4/6 peak timings and all NSE over 0.96.
BEE001_01675	✘		✘	Good match on peaks (5/6 within 10%). Good match for 4/6 peak timings and NSE over 0.89
ELI001_20608	✓	Significant vegetation attenuating flows.	✘	Good match on peaks (all within 5%). Unable to replicate peak timing although all NSE over 0.97.
ELI001_16541	✓	Very large catchment area upstream of this location with significant depth in-channel.	✘	Good match on peaks (all within 5%). Unable to replicate peak timing although all NSE over 0.94.
ELI001_15535	✘		✘	Good match on peaks (all within 5%). Unable to replicate peak timing although all NSE over 0.95.
ELI001_09496	✓	Flat terrain attenuating flows. Complex floodplain interaction and breakouts also evident.	✘	Reasonable match on peaks (all within 40%). Unable to replicate peak timing or shape with complex floodplain interactions. Breakout flow immediately upstream directs water towards ELI011

POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
ELI001_00000	✗	Flat terrain attenuating flows. Complex floodplain interaction and breakouts also evident.	✗	Reasonable match on peaks (all within 50%). Unable to replicate peak timing or shape with complex floodplain interactions. Breakout flow immediately upstream directs water towards ELI011
NIN001_12891	✓	Flat terrain upstream and presence of bunds and existing storages attenuating flows.	✗	Good match on peaks (4/6 within 10%). All peak timings differences under 30 minutes.
NIN001_09018	✓	Flat terrain attenuating flows. Complex floodplain interaction and breakouts to the north also evident.	✗	Reasonable match on peaks (all within 20%). Unable to replicate peak timing or shape with complex floodplain interactions.
NIN001_04346	✗		✗	Reasonable match on peaks (all within 30%). Unable to replicate peak timing or shape with complex floodplain interactions.
NIN001_00000	✗		✗	Reasonable match on peaks (all within 20%). Unable to replicate peak timing or shape with complex floodplain interactions and tailwater influence.
GMC001_10647	✓	Significant vegetation attenuating flows upstream of this location.	✗	Good match on peaks (all within 5%). Unable to replicate peak timing for single event although all NSE over 0.93.
GMC001_05586	✓	Flat terrain attenuating flows.	✗	Good match on peaks (4/6 within 10%). Unable to replicate peak timing for 4/6 events although all NSE over 0.93.

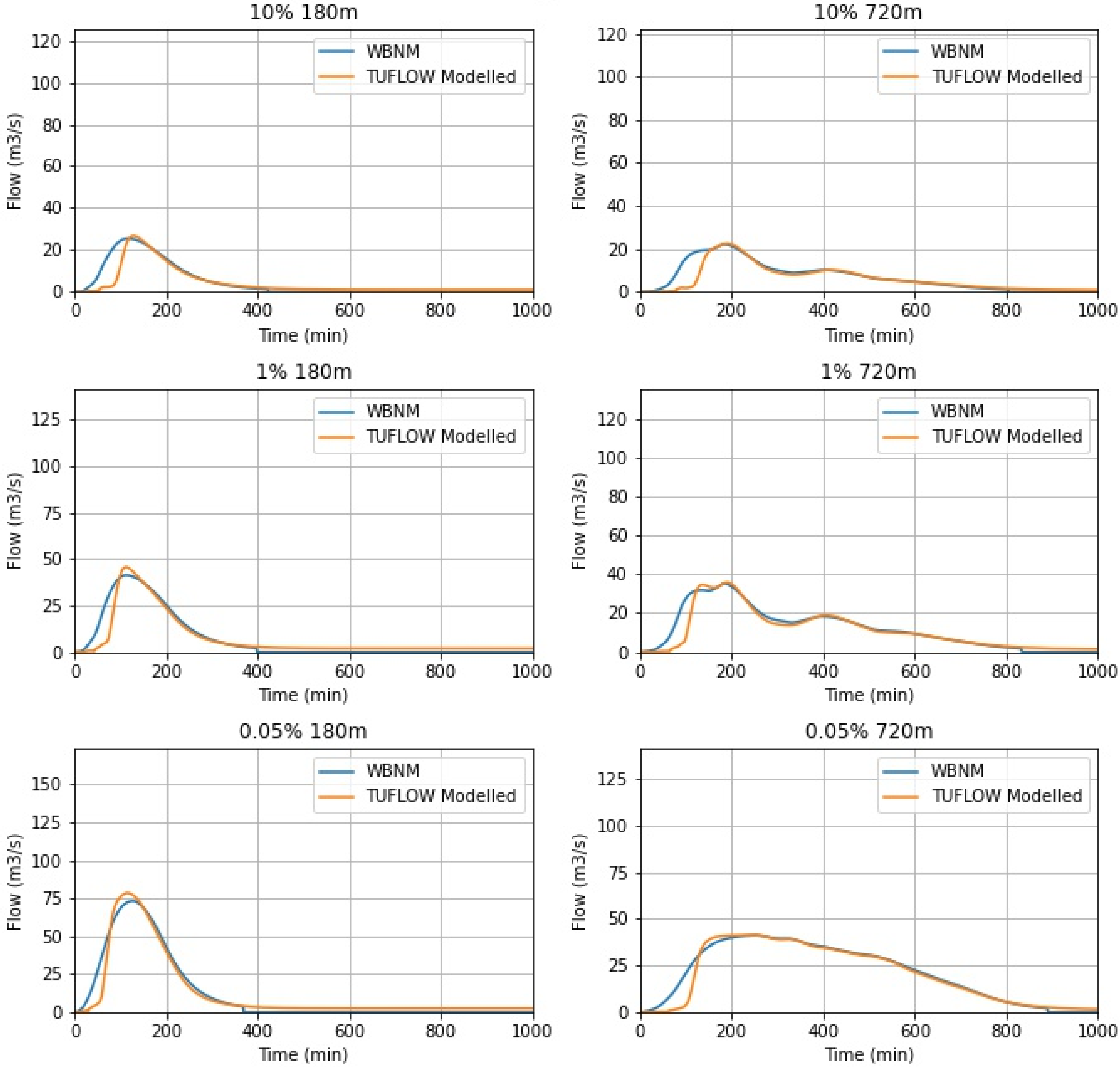
POI	Artificial Storage Required?	Storage description	HEH criteria met?	Description of results
GMC001_00319	✘		✘	Reasonable match on peaks (all within 20%). Unable to replicate peak timing or shape with complex floodplain interactions and tailwater influence.
ELI011_00873	✘		✘	Poor match, breakout floodplain flows in TUFLOW unable to be replicated. Flows include breakout from ELI001. Initial hydrograph shape for local flows is reasonable.
ELI011_00000	✘		✘	Poor match, breakout floodplain flows in TUFLOW unable to be replicated. Flows include breakout from ELI001. Initial hydrograph shape for local flows is reasonable.

SMC034_00000



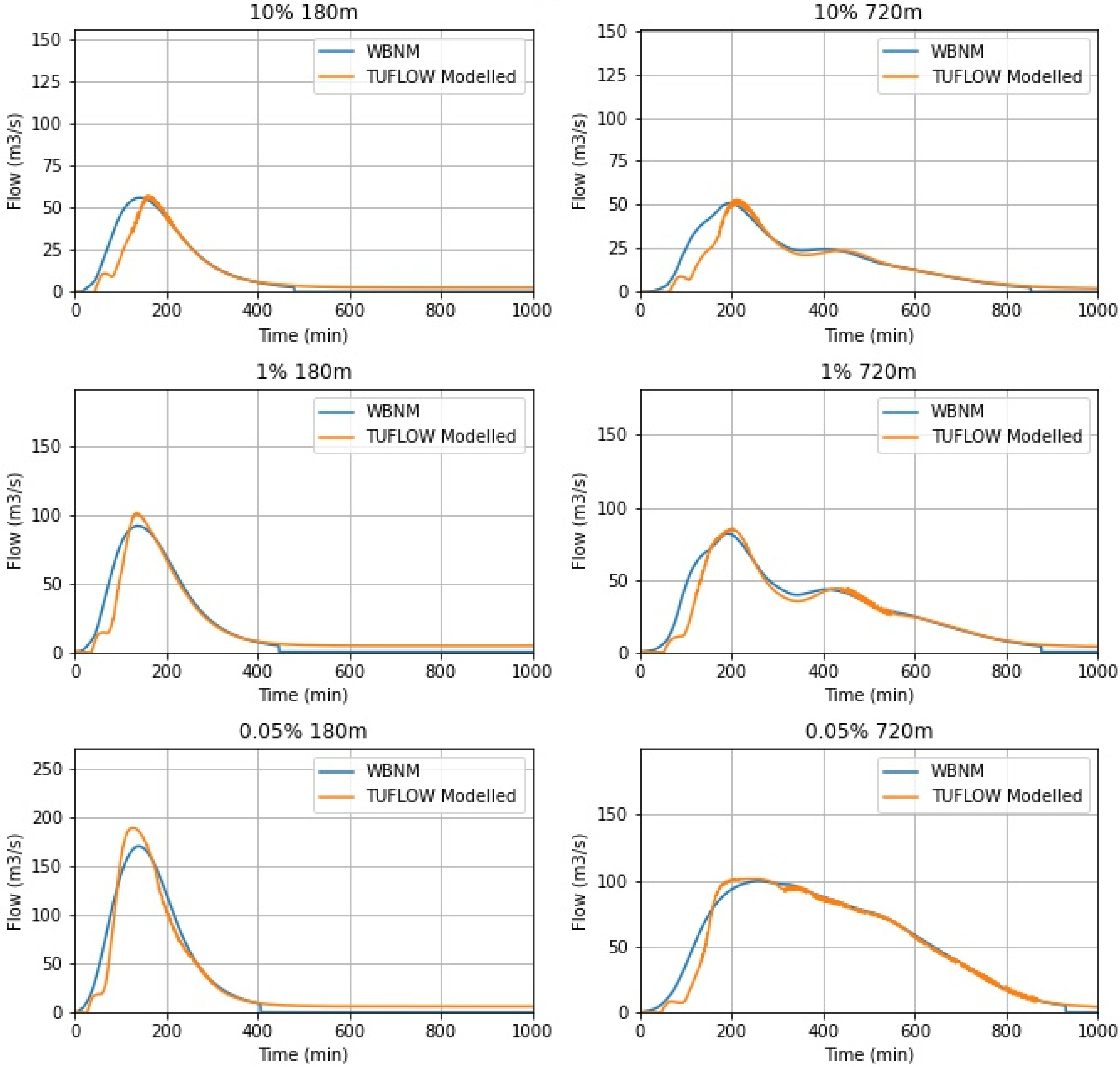
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	1.8%	12.0min	0.92
10% 720m	7.98%	1.0min	0.92
1% 180m	10.68%	10.0min	0.93
1% 720m	6.51%	4.0min	0.95
0.05% 180m	14.22%	19.0min	0.93
0.05% 720m	0.68%	21.0min	0.97

SMC020_03707



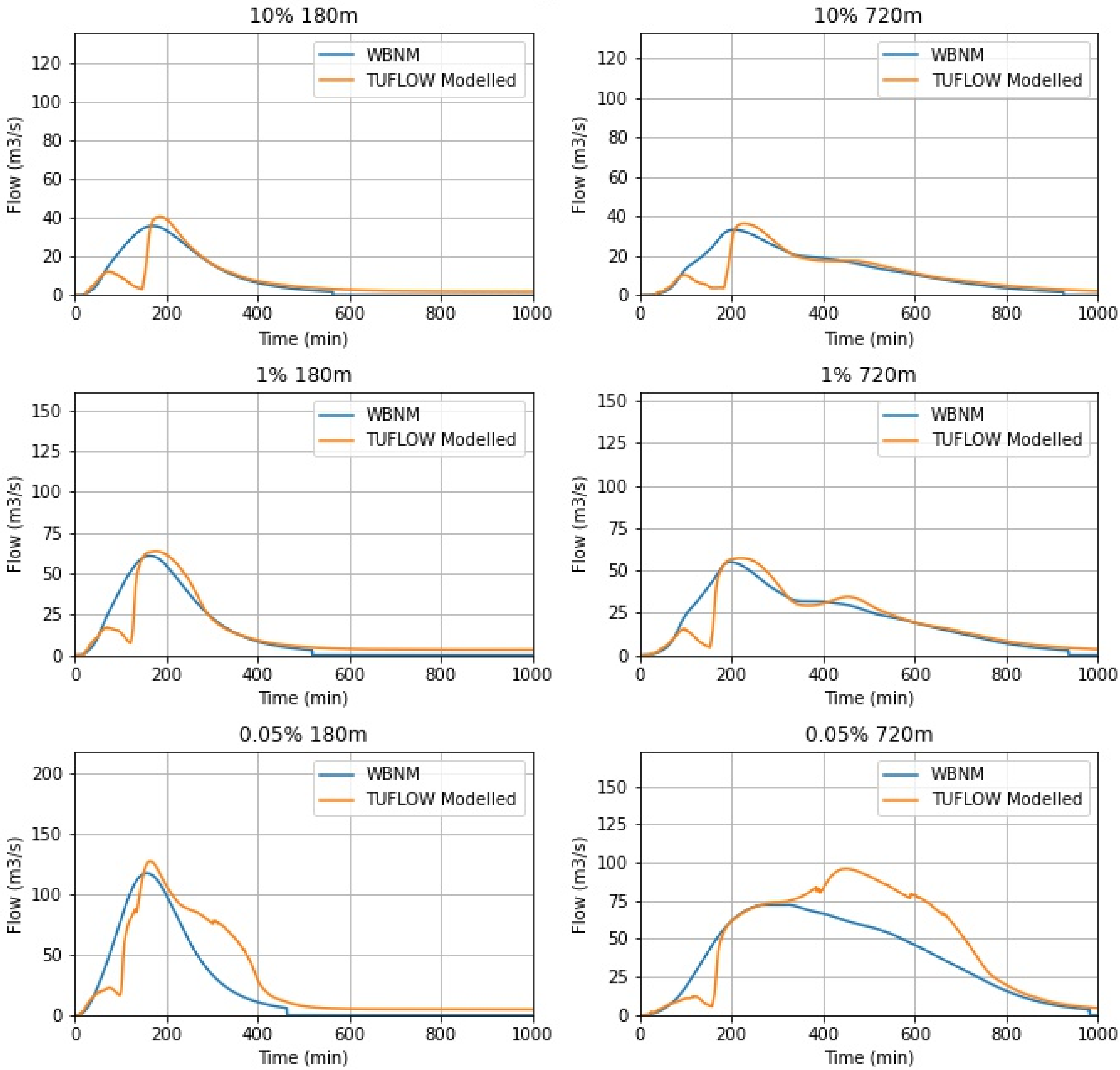
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	5.14%	13.0min	0.71
10% 720m	1.36%	7.0min	0.71
1% 180m	10.42%	1.0min	0.87
1% 720m	1.53%	6.0min	0.87
0.05% 180m	7.18%	11.0min	0.95
0.05% 720m	0.4%	0.0min	0.95

SMC020_01371



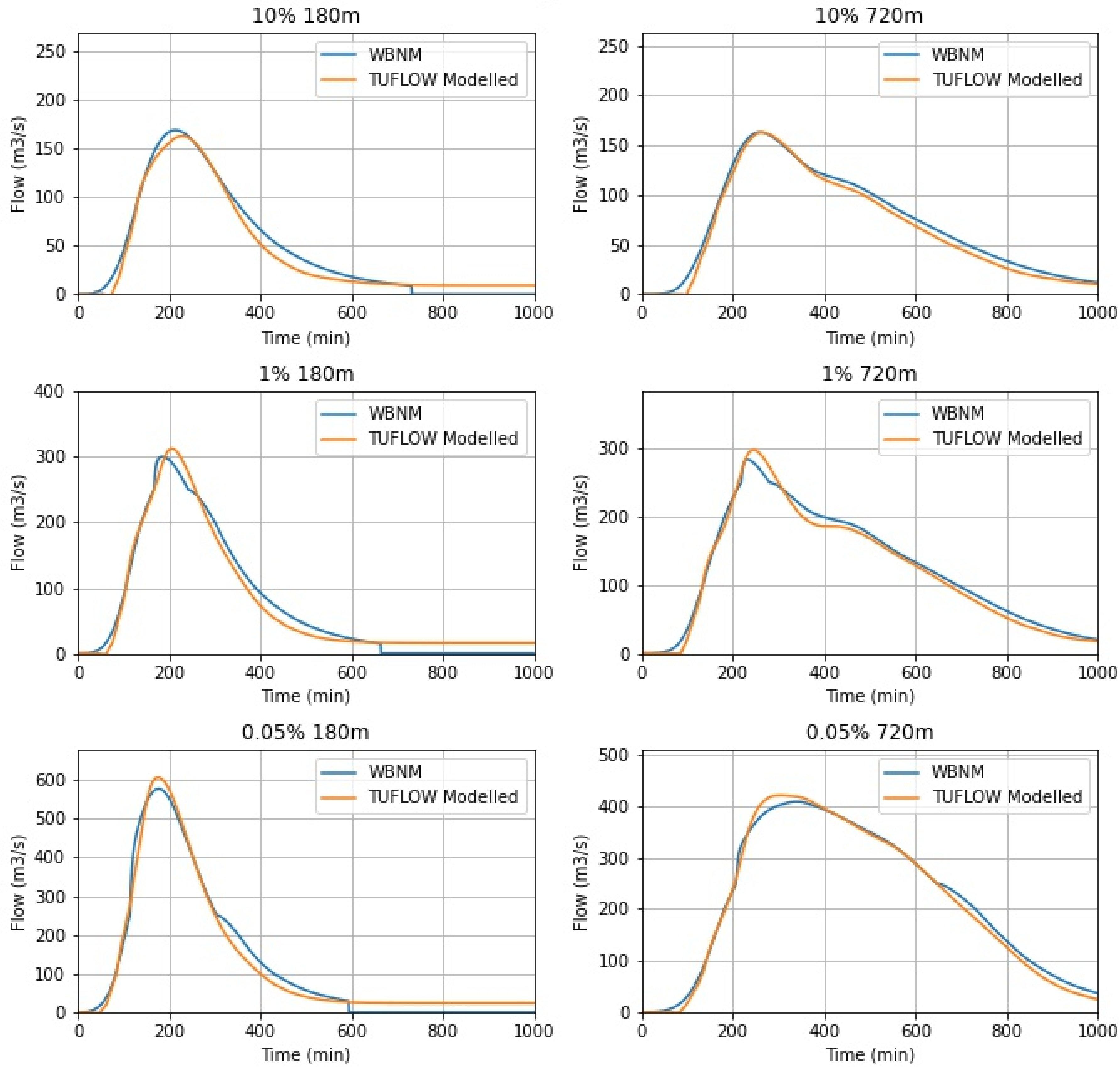
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	2.4%	16.0min	0.81
10% 720m	4.24%	16.0min	0.82
1% 180m	10.17%	2.0min	0.91
1% 720m	4.17%	13.0min	0.91
0.05% 180m	11.06%	11.0min	0.96
0.05% 720m	1.63%	7.0min	0.96

SMC009_02155



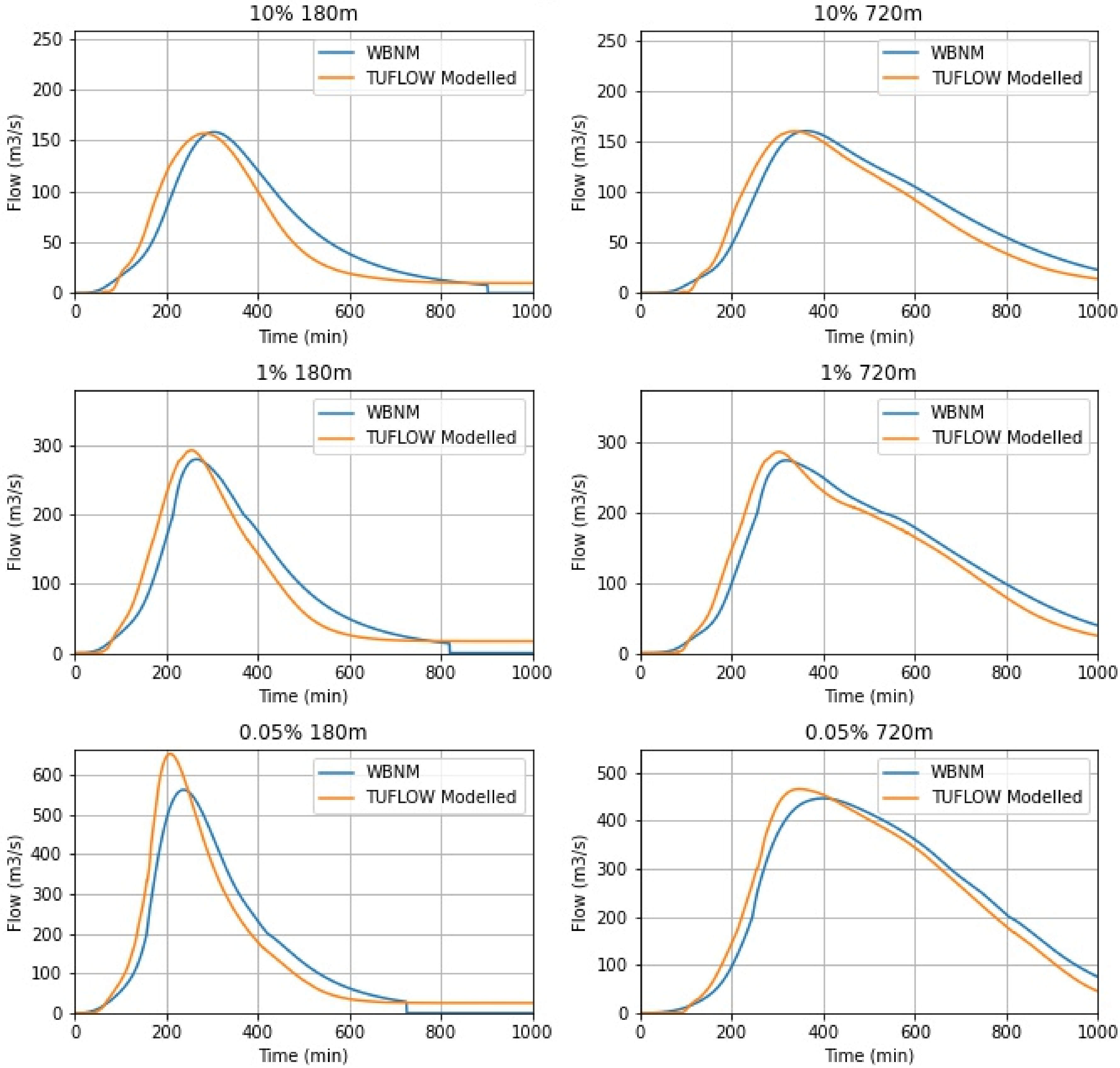
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	13.26%	15.0min	0.59
10% 720m	9.62%	21.0min	0.62
1% 180m	4.46%	14.0min	0.8
1% 720m	4.24%	22.0min	0.81
0.05% 180m	8.37%	9.0min	0.74
0.05% 720m	32.89%	126.0min	0.71

SMC001_16170



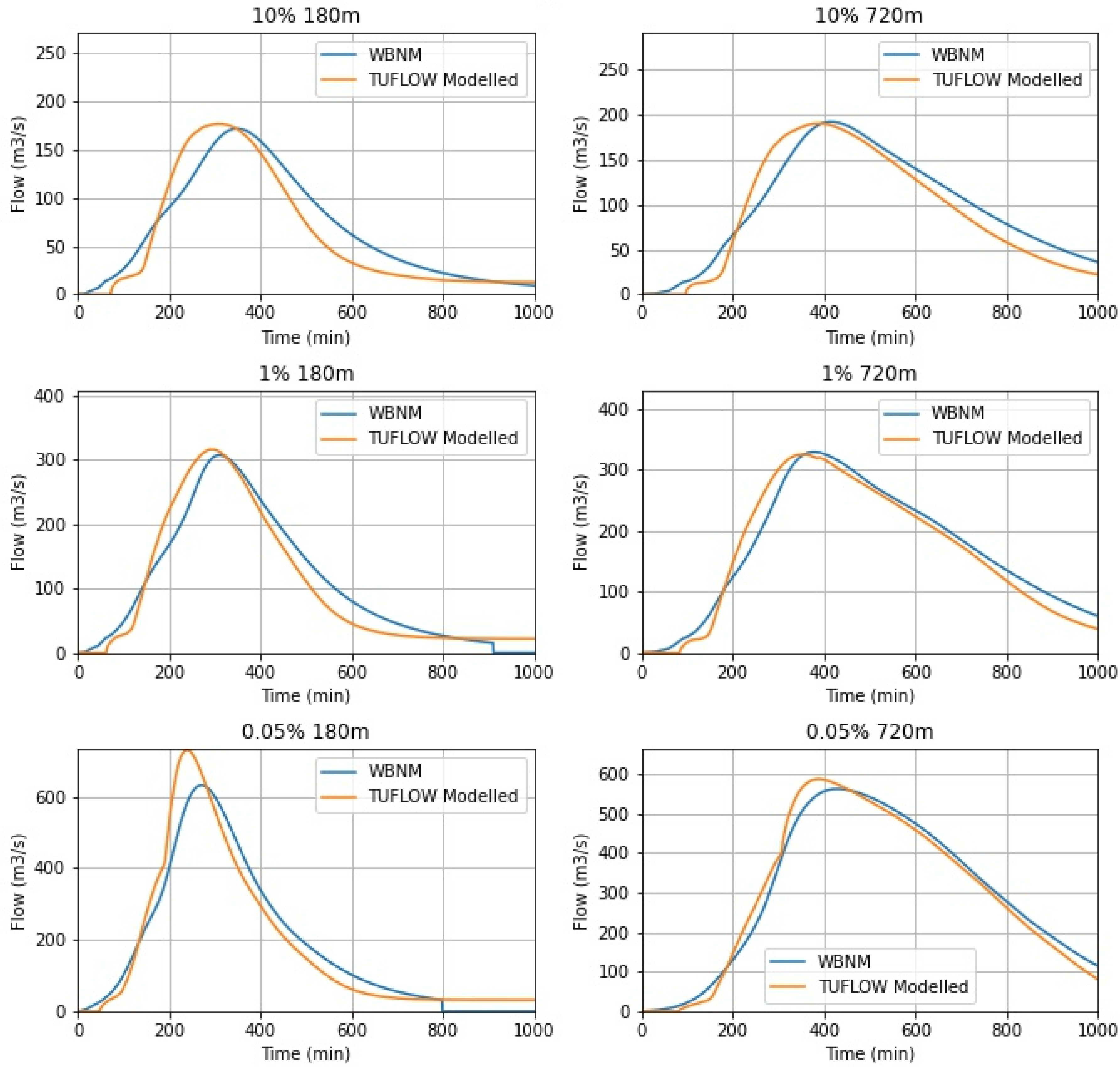
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	3.64%	13.0min	0.97
10% 720m	0.21%	3.0min	0.99
1% 180m	4.1%	21.0min	0.97
1% 720m	4.97%	13.0min	0.99
0.05% 180m	5.12%	1.0min	0.98
0.05% 720m	3.01%	36.0min	0.99

SMC001_13467



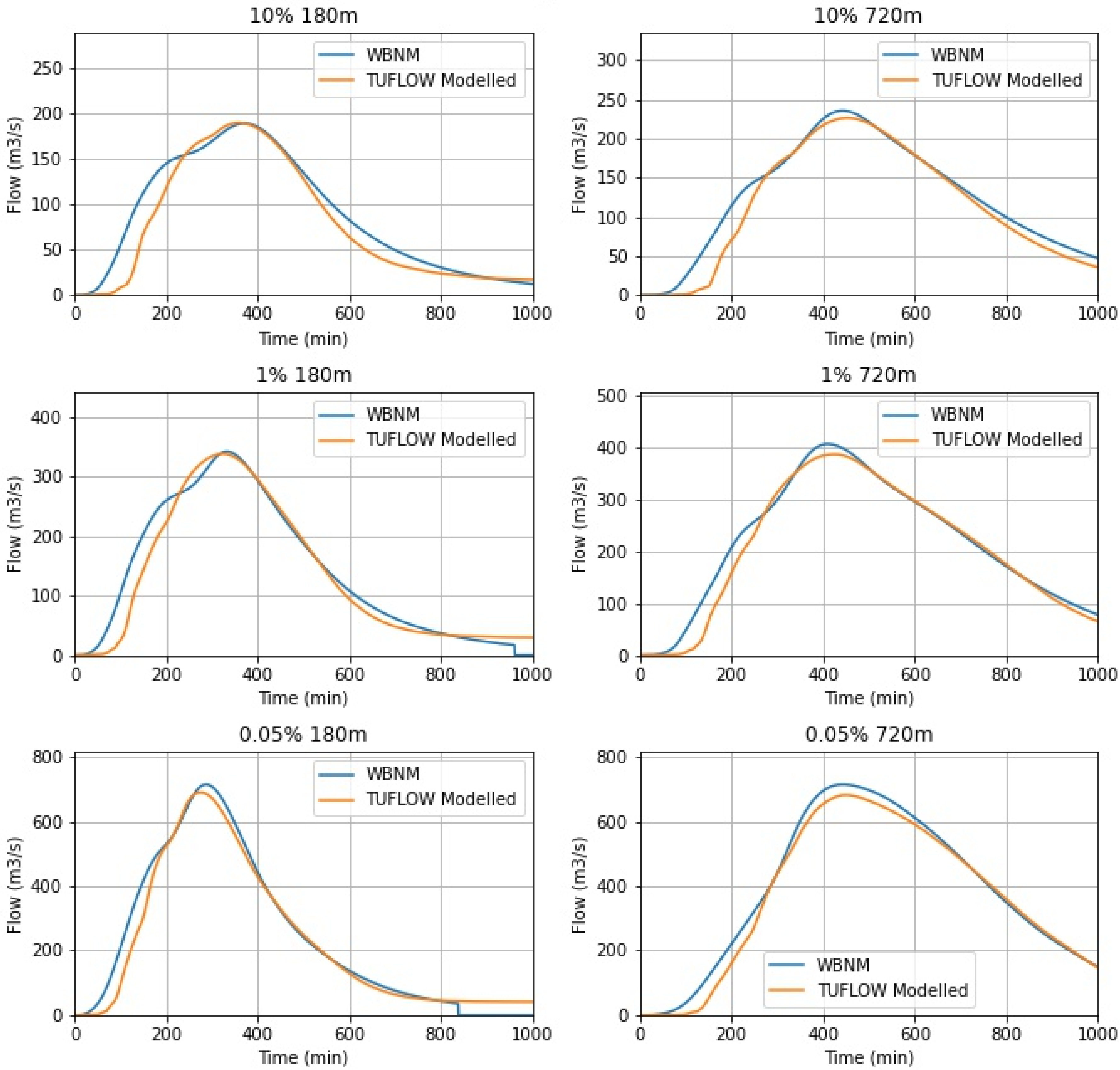
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	0.82%	20.0min	0.9
10% 720m	0.2%	27.0min	0.93
1% 180m	4.75%	11.0min	0.92
1% 720m	4.39%	17.0min	0.95
0.05% 180m	16.16%	29.0min	0.91
0.05% 720m	4.32%	53.0min	0.97

SMC001_10051



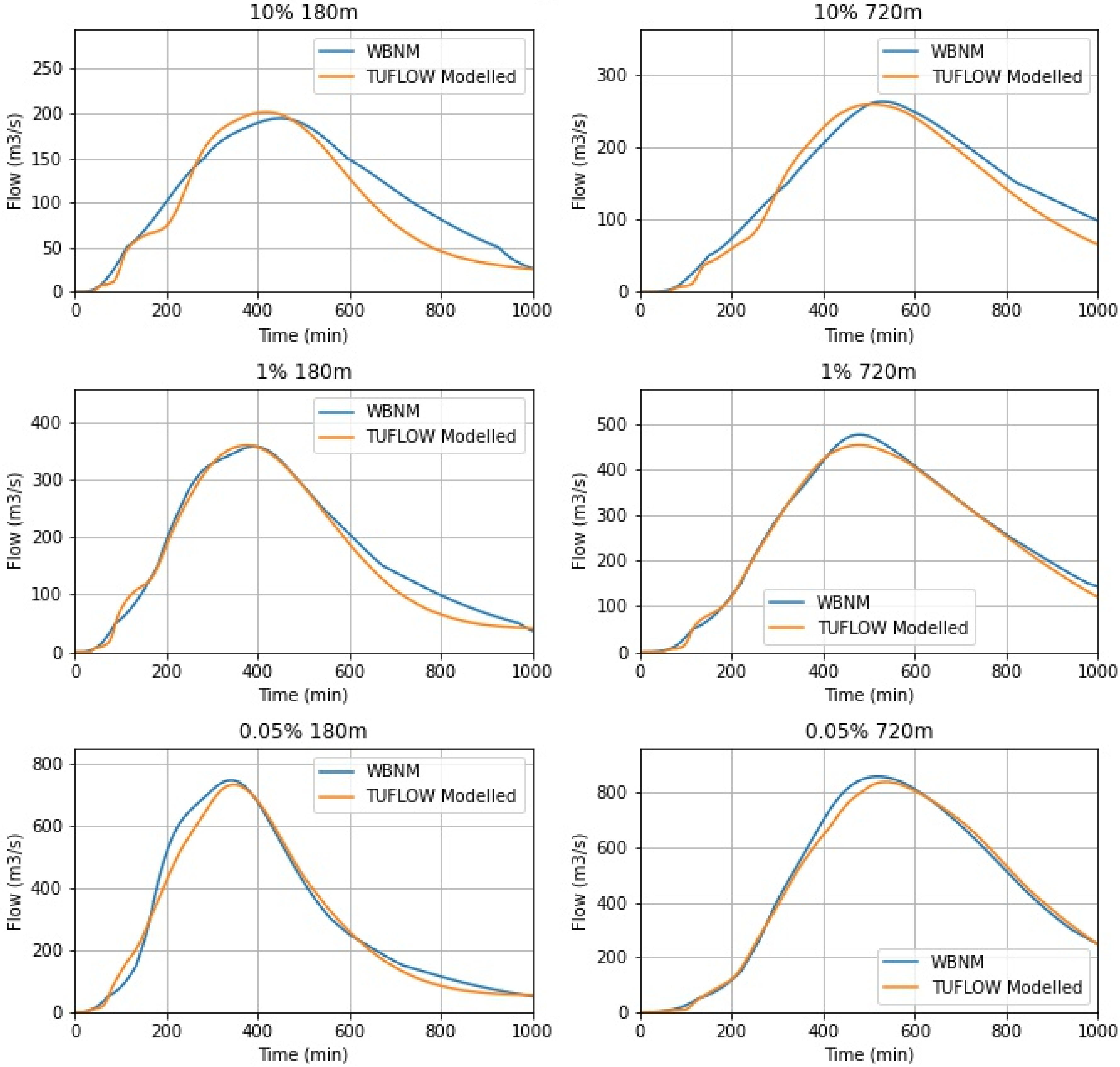
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	2.84%	39.0min	0.89
10% 720m	0.89%	25.0min	0.93
1% 180m	2.88%	16.0min	0.94
1% 720m	1.15%	24.0min	0.96
0.05% 180m	15.55%	31.0min	0.94
0.05% 720m	4.45%	42.0min	0.98

SMC001_06731



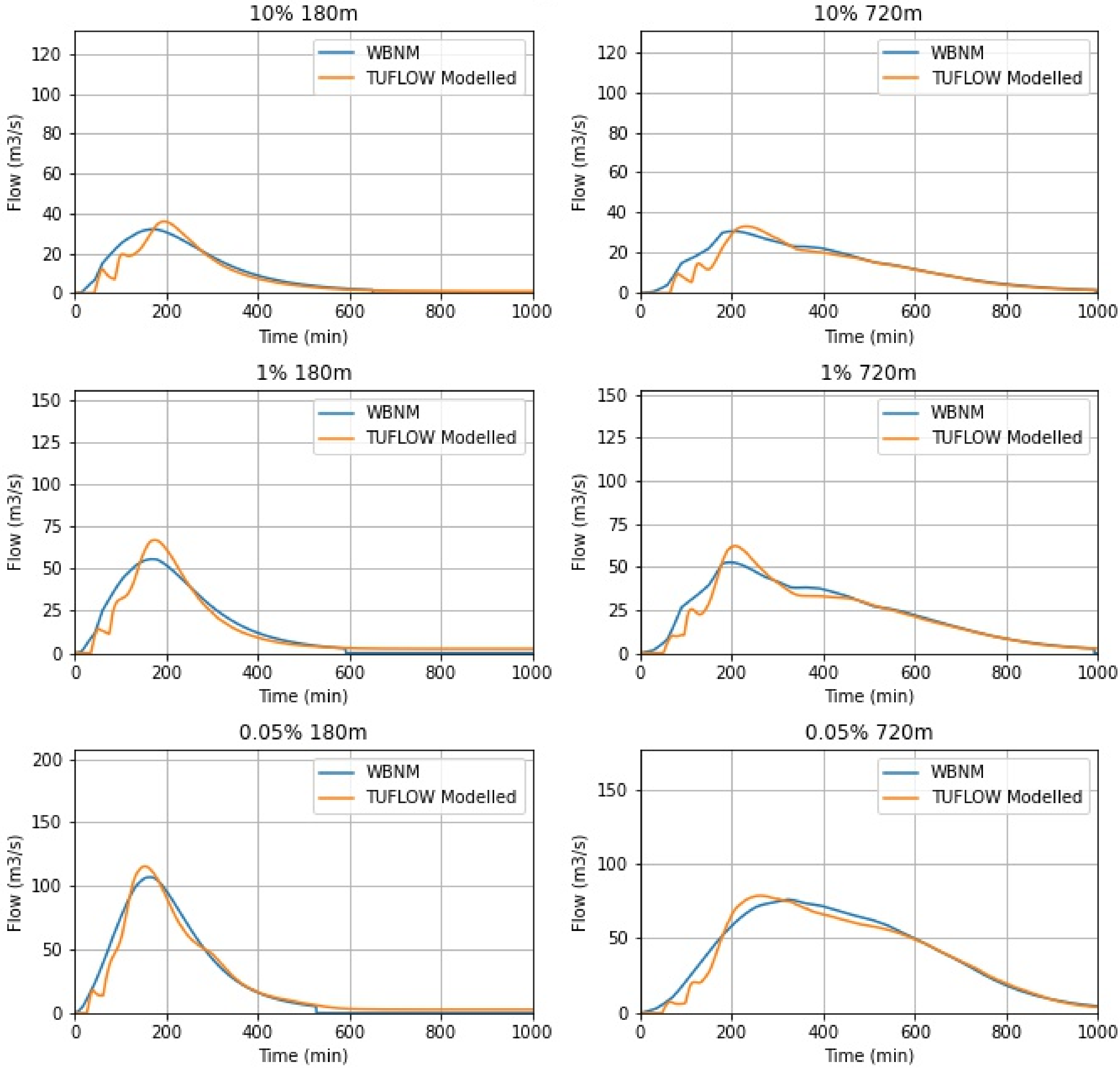
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	0.28%	14.0min	0.92
10% 720m	3.84%	11.0min	0.95
1% 180m	1.05%	9.0min	0.95
1% 720m	4.87%	15.0min	0.97
0.05% 180m	3.46%	11.0min	0.97
0.05% 720m	4.56%	7.0min	0.98

SMC001_02671



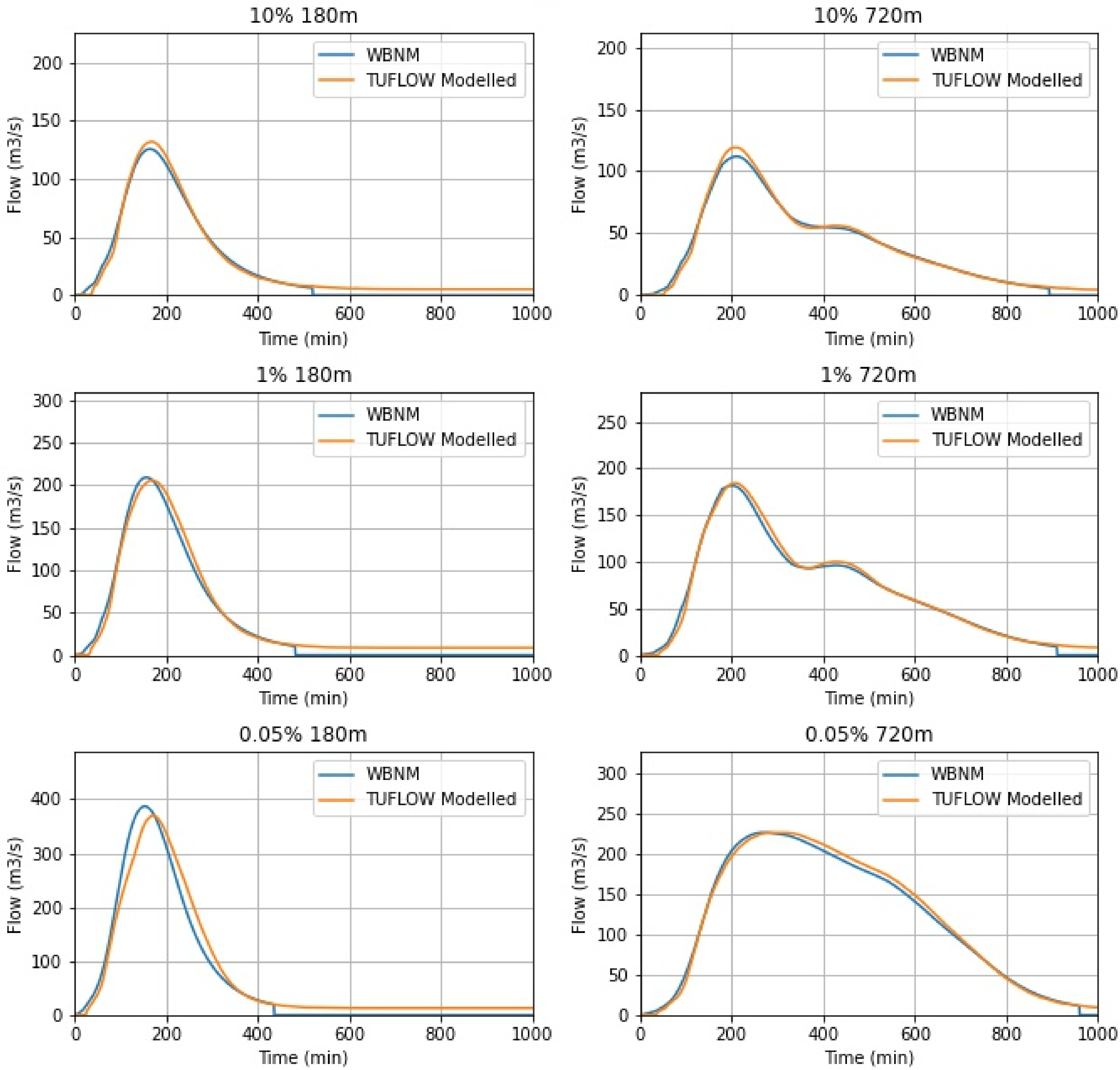
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	3.55%	30.0min	0.9
10% 720m	1.37%	25.0min	0.96
1% 180m	0.59%	16.0min	0.98
1% 720m	4.8%	3.0min	1.0
0.05% 180m	1.9%	7.0min	0.98
0.05% 720m	2.3%	18.0min	0.99

BEE018_01396



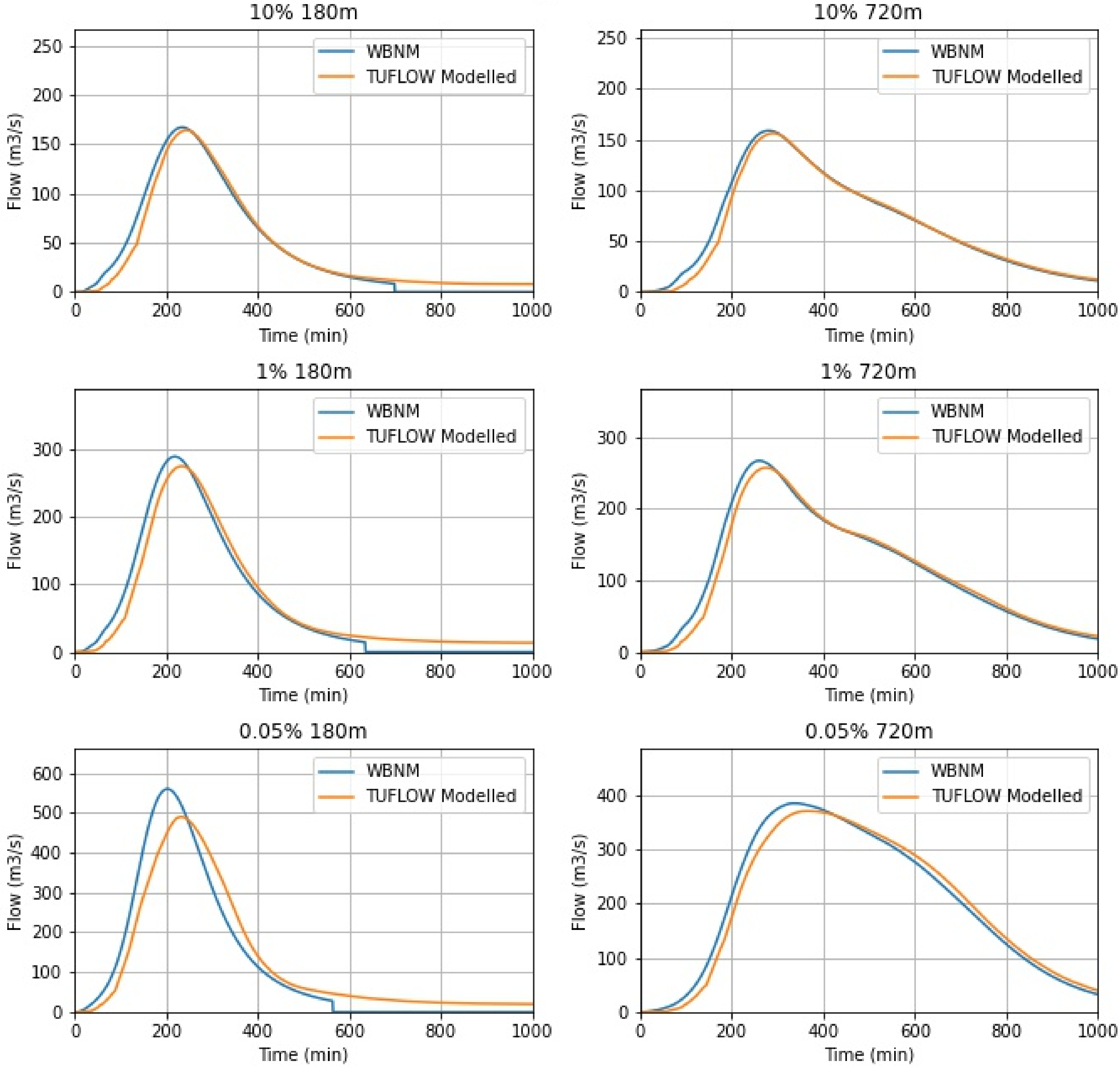
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	12.37%	24.0min	0.9
10% 720m	8.02%	29.0min	0.9
1% 180m	20.31%	7.0min	0.93
1% 720m	18.13%	12.0min	0.93
0.05% 180m	8.0%	12.0min	0.97
0.05% 720m	3.38%	62.0min	0.97

BEE001_06814



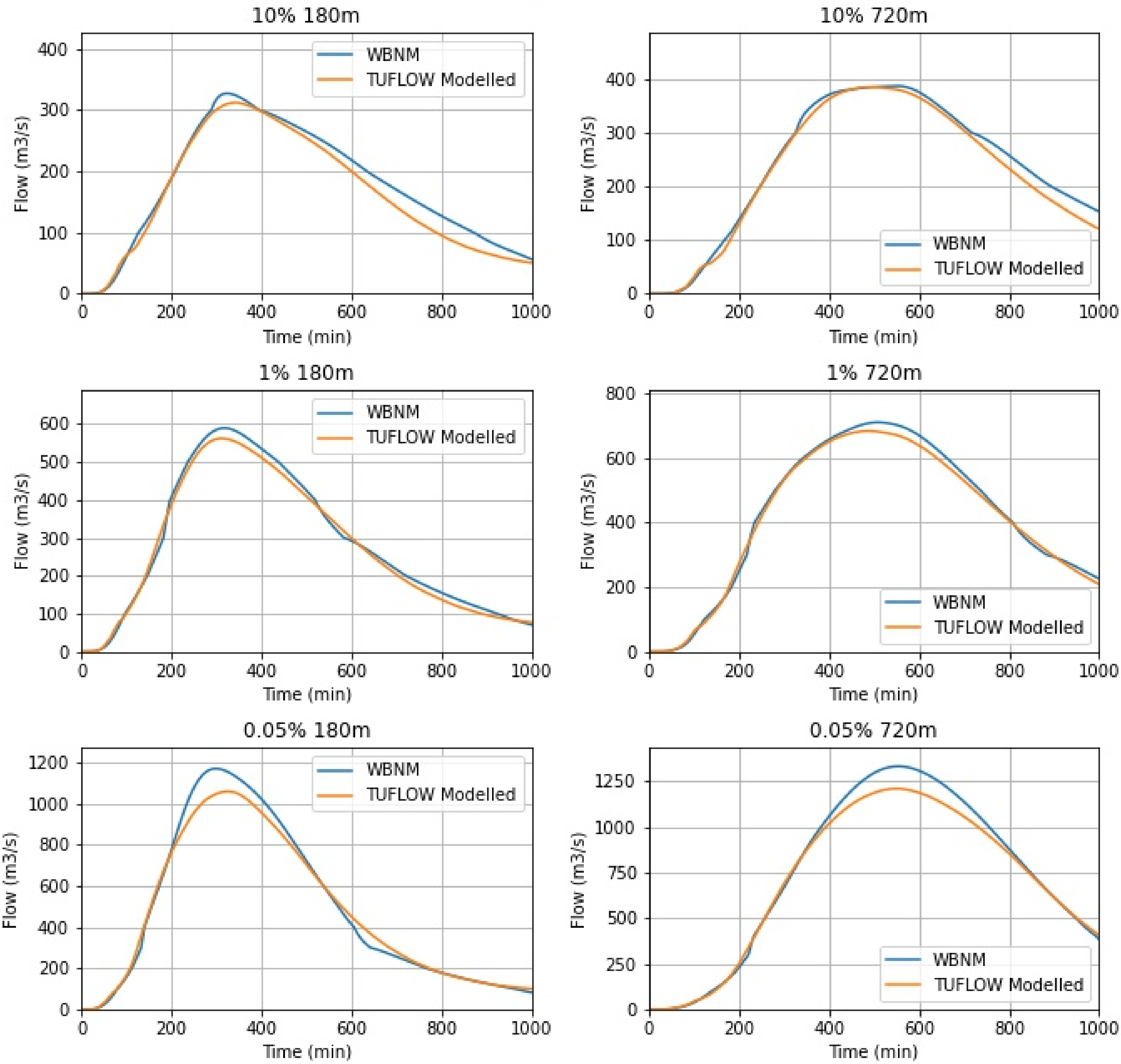
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	4.92%	3.0min	0.98
10% 720m	6.56%	1.0min	0.99
1% 180m	1.65%	14.0min	0.98
1% 720m	1.5%	7.0min	0.99
0.05% 180m	4.45%	18.0min	0.96
0.05% 720m	0.04%	27.0min	1.0

BEE001_01675



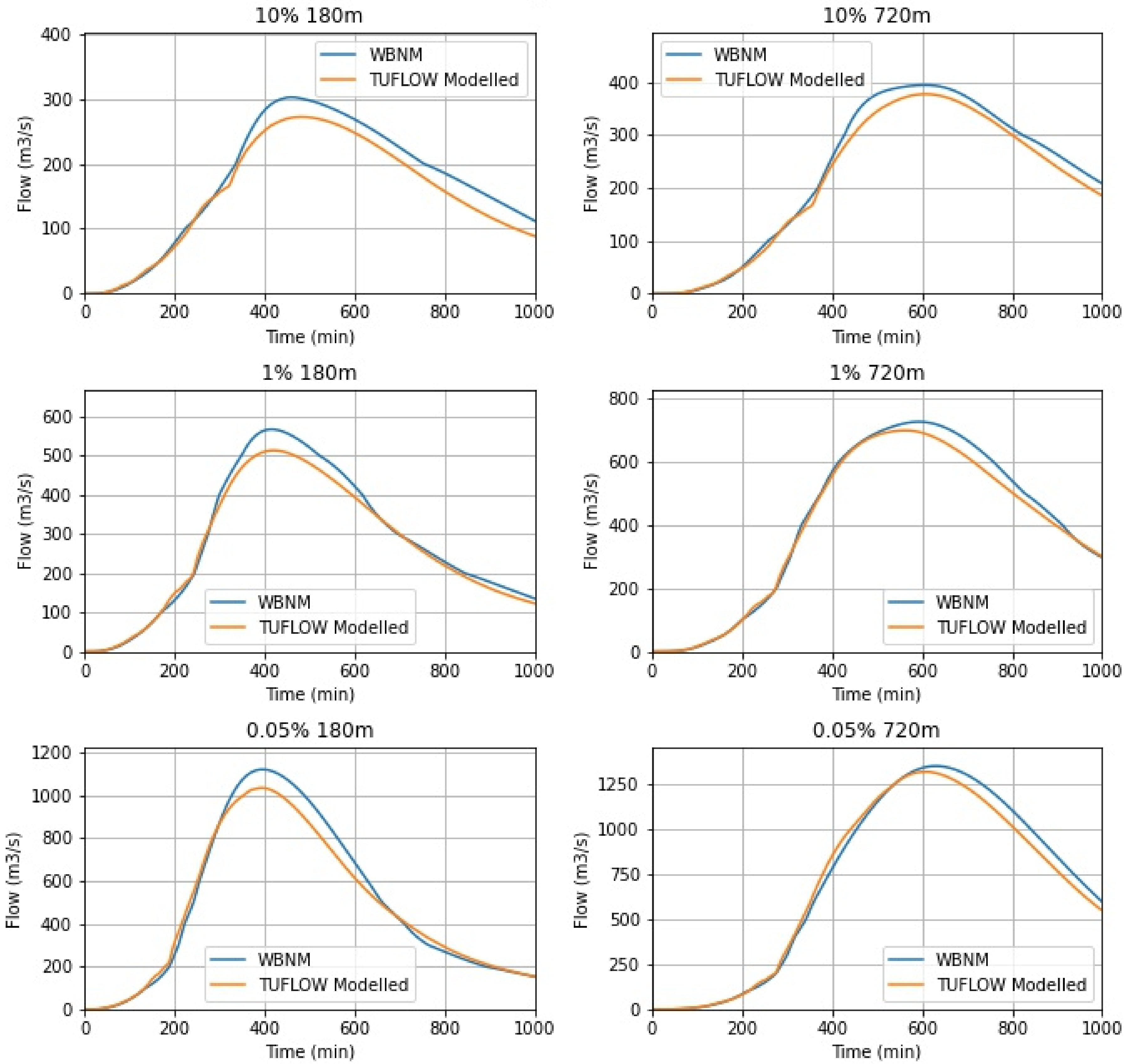
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	1.68%	8.0min	0.97
10% 720m	1.63%	10.0min	0.98
1% 180m	4.93%	14.0min	0.96
1% 720m	3.69%	14.0min	0.98
0.05% 180m	12.52%	30.0min	0.89
0.05% 720m	3.71%	29.0min	0.98

ELI001_20608



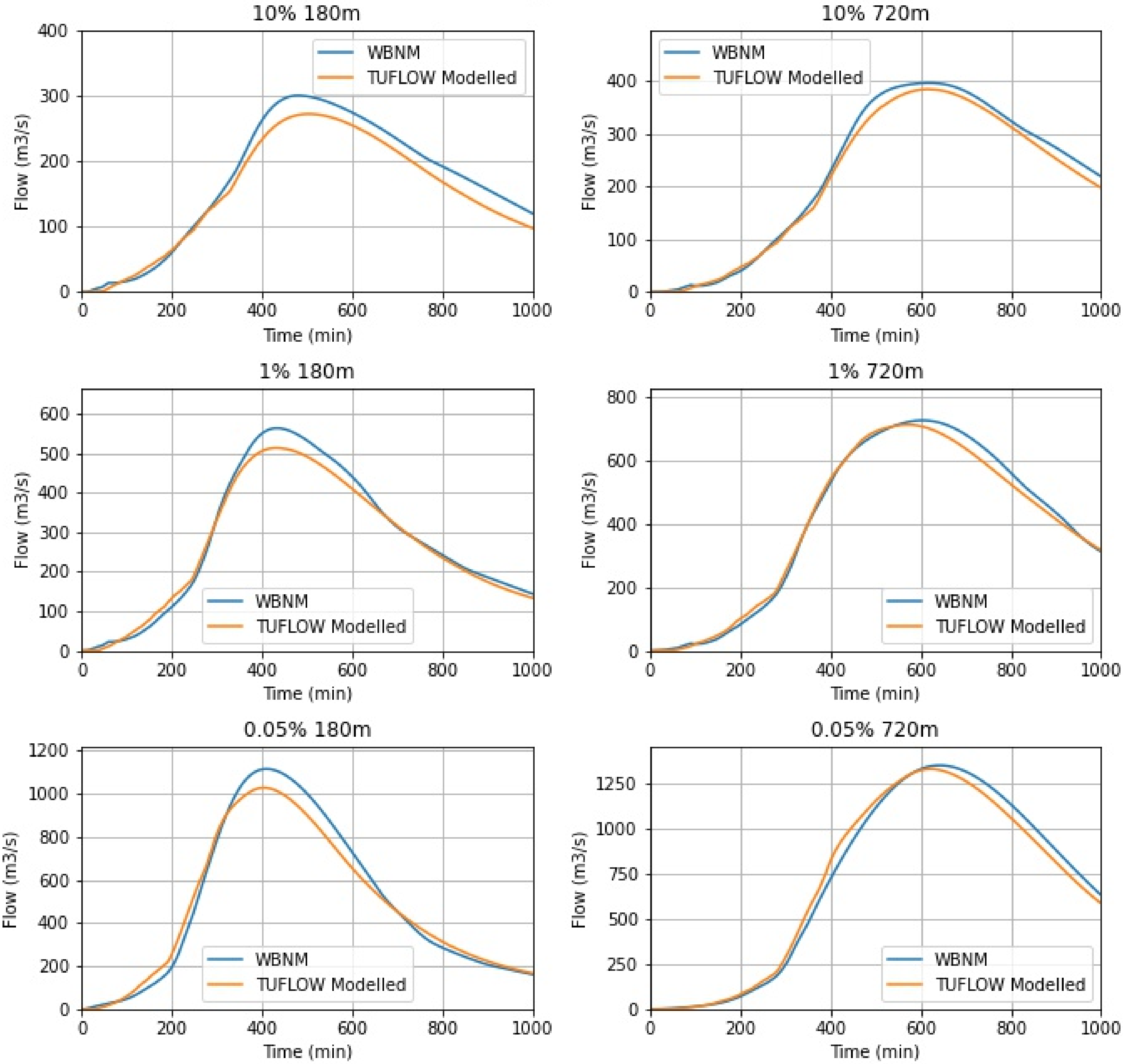
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	4.61%	18.0min	0.97
10% 720m	0.51%	60.0min	0.99
1% 180m	4.64%	5.0min	0.99
1% 720m	3.78%	22.0min	0.99
0.05% 180m	9.5%	26.0min	0.98
0.05% 720m	9.19%	5.0min	0.98

ELI001_16541



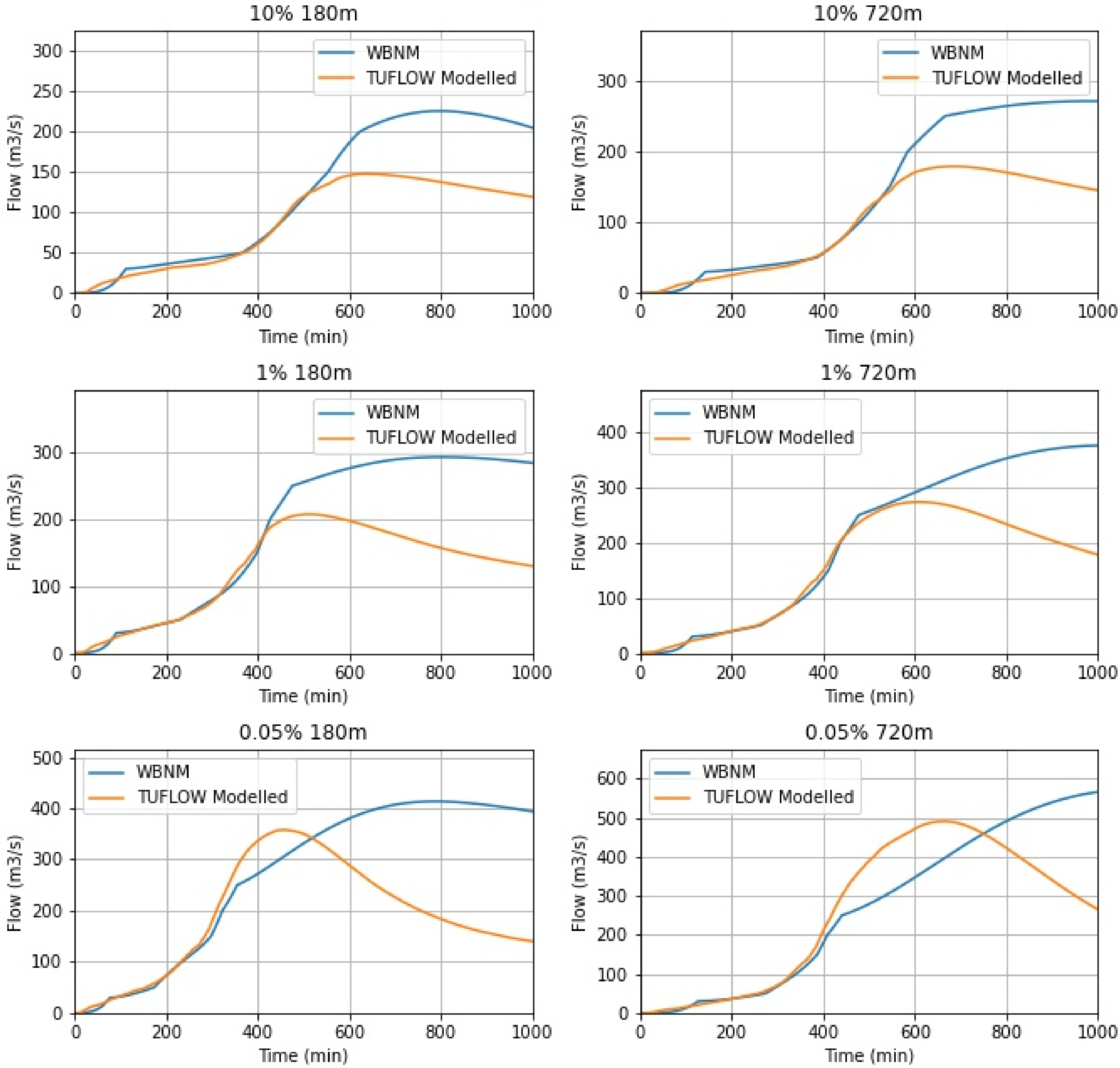
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	10.01%	24.0min	0.94
10% 720m	4.34%	1.0min	0.98
1% 180m	9.49%	5.0min	0.98
1% 720m	3.77%	30.0min	0.99
0.05% 180m	7.69%	3.0min	0.98
0.05% 720m	2.37%	21.0min	0.99

ELI001_15535



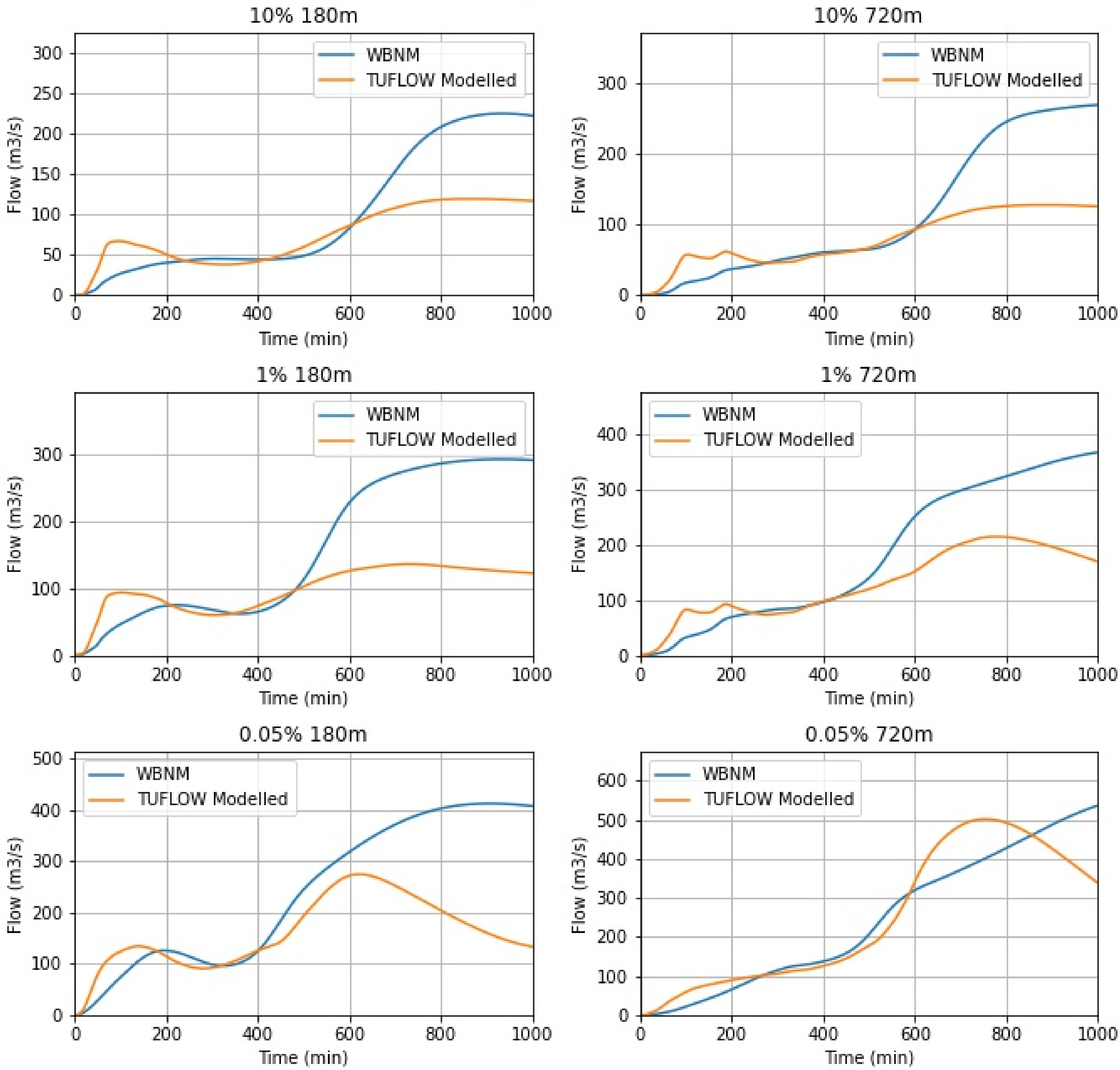
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	9.45%	23.0min	0.95
10% 720m	3.0%	0.0min	0.99
1% 180m	8.9%	1.0min	0.98
1% 720m	1.89%	31.0min	0.99
0.05% 180m	7.82%	5.0min	0.97
0.05% 720m	1.49%	20.0min	0.99

ELI001_09496



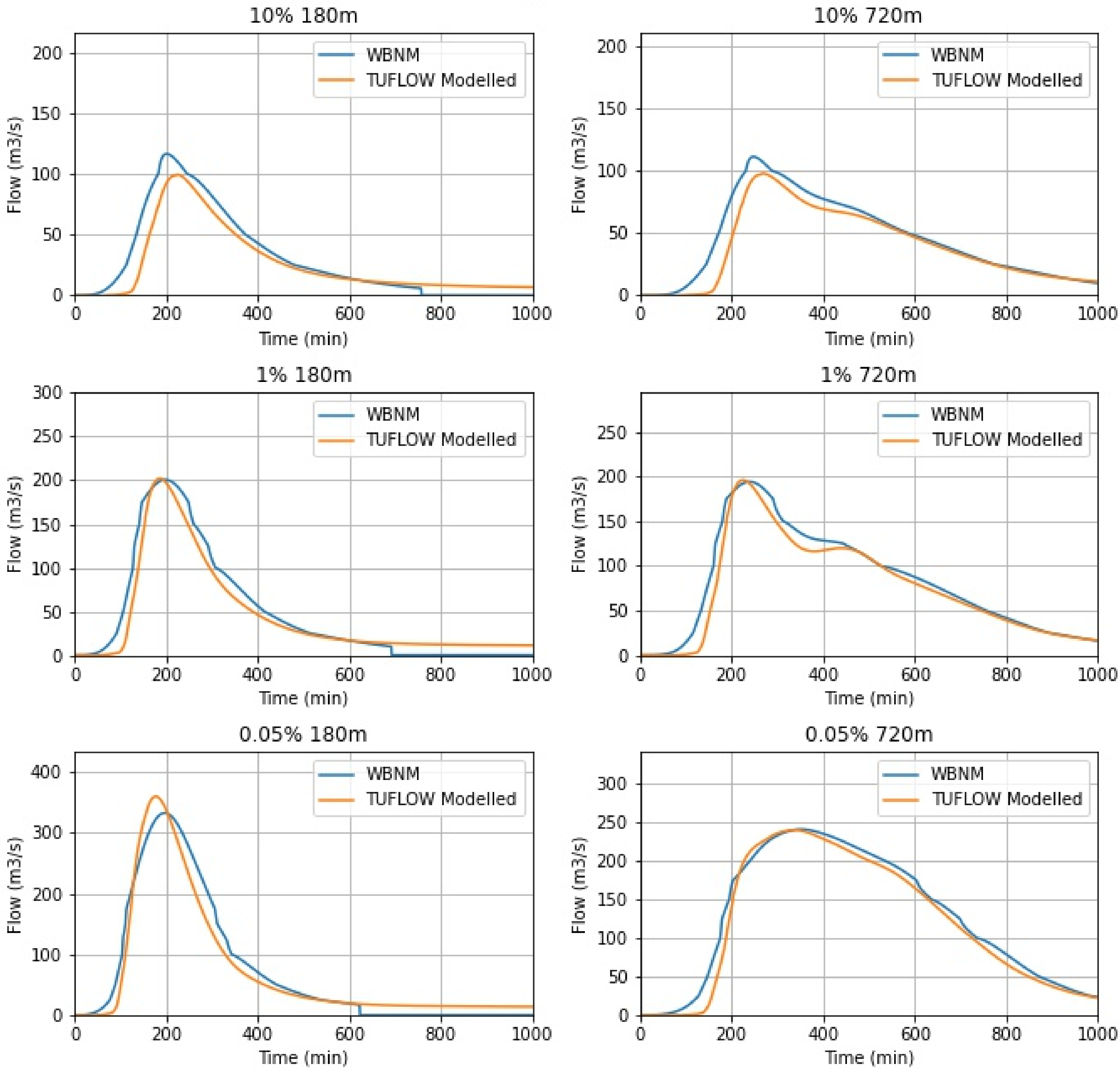
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	34.53%	155.0min	0.32
10% 720m	33.96%	294.0min	0.39
1% 180m	29.16%	294.0min	0.07
1% 720m	27.29%	403.0min	0.44
0.05% 180m	13.52%	331.0min	-0.1
0.05% 720m	14.4%	422.0min	0.64

ELI001_00000



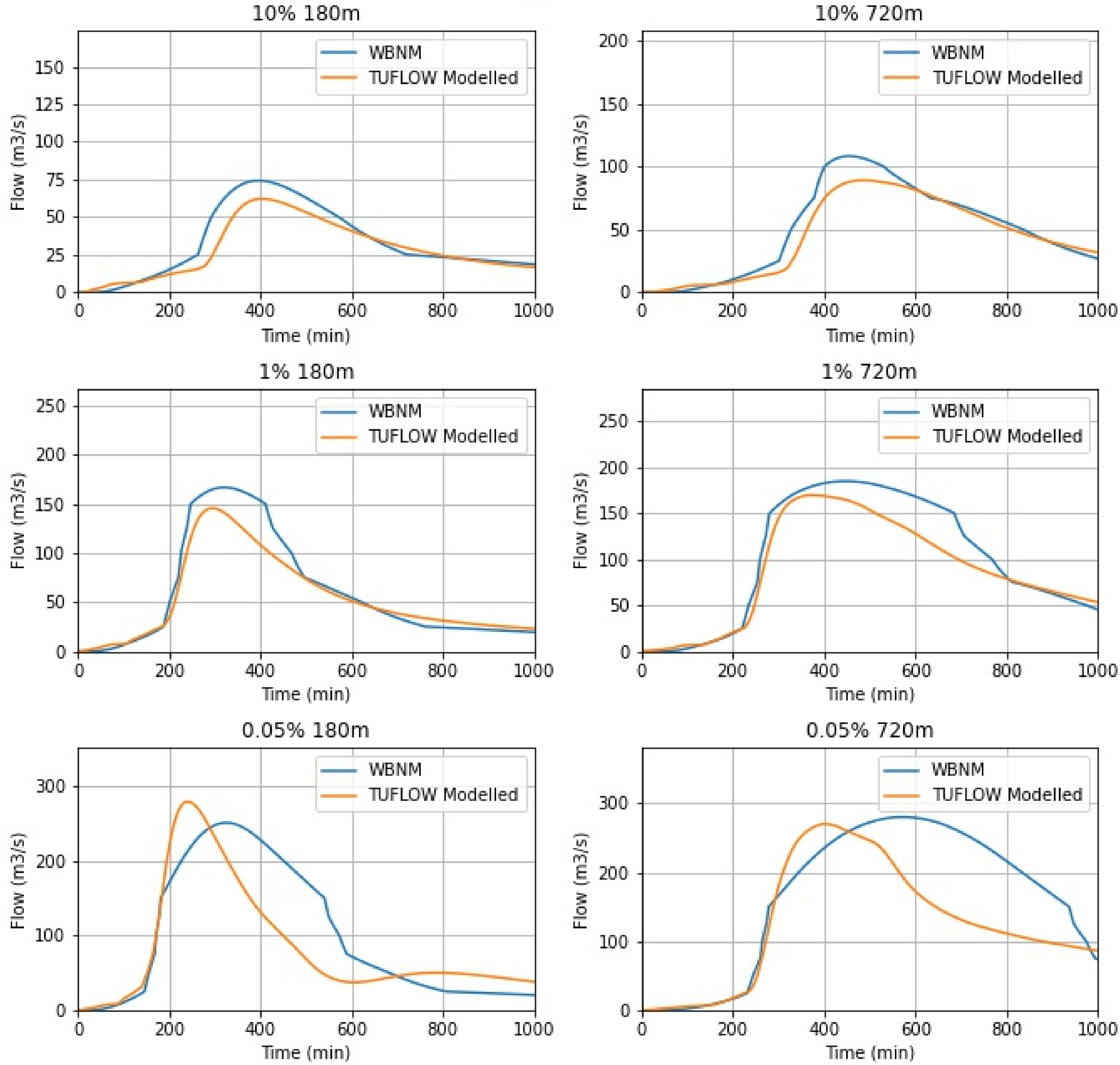
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	46.96%	67.0min	-0.65
10% 720m	52.93%	223.0min	-0.88
1% 180m	53.51%	195.0min	-1.08
1% 720m	42.9%	351.0min	-0.17
0.05% 180m	33.42%	282.0min	-0.59
0.05% 720m	12.43%	437.0min	0.86

NIN001_12891



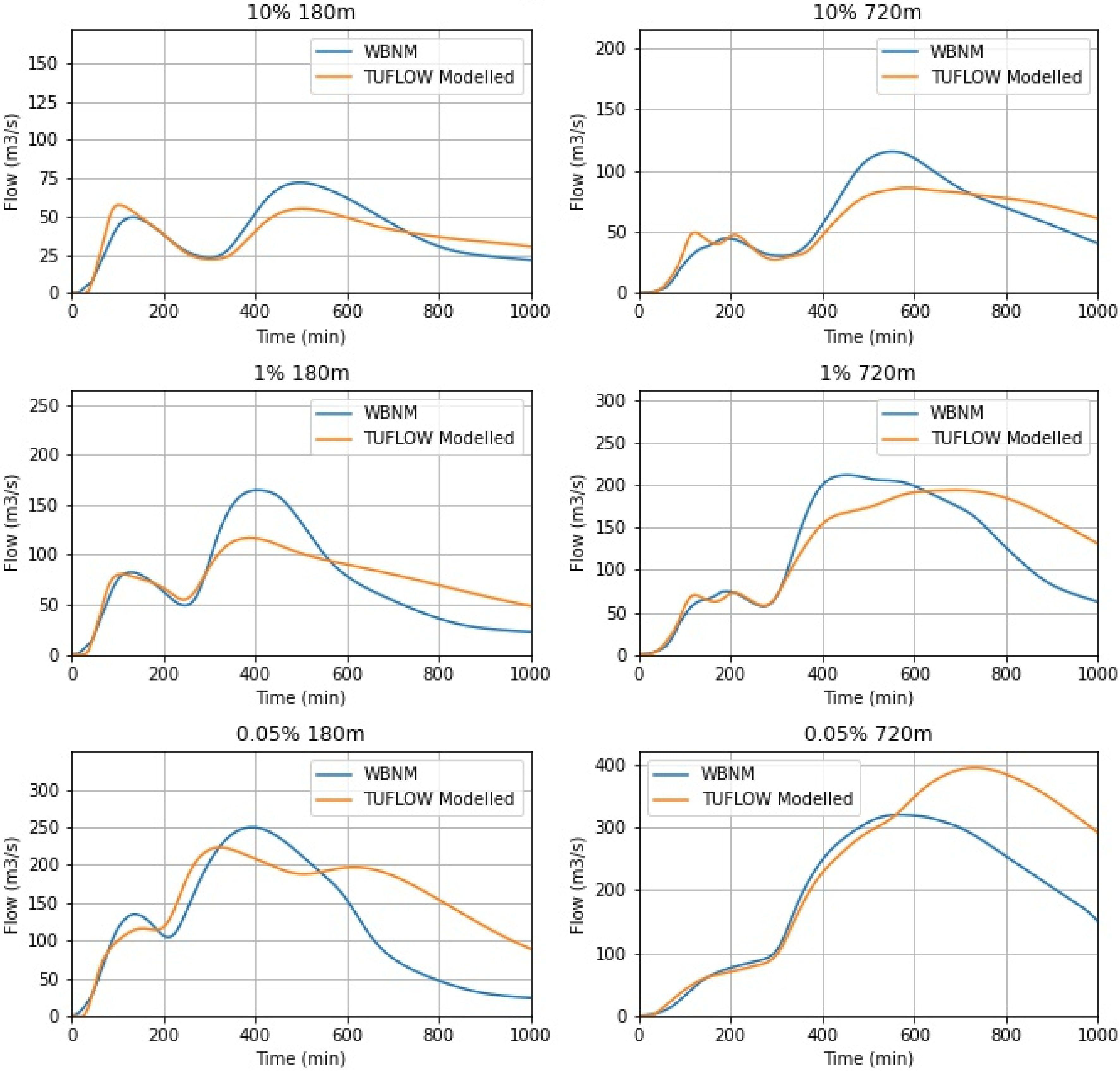
	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	14.65%	23.0min	0.81
10% 720m	12.08%	19.0min	0.86
1% 180m	0.69%	12.0min	0.93
1% 720m	0.95%	13.0min	0.95
0.05% 180m	8.17%	20.0min	0.95
0.05% 720m	0.42%	15.0min	0.98

NIN001_09018



	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	16.3%	8.0min	0.79
10% 720m	17.79%	30.0min	0.89
1% 180m	12.7%	25.0min	0.86
1% 720m	8.21%	74.0min	0.86
0.05% 180m	11.29%	85.0min	0.57
0.05% 720m	3.59%	169.0min	0.51

NIN001_04346



	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	20.31%	394.0min	0.5
10% 720m	25.54%	33.0min	0.66
1% 180m	29.07%	15.0min	-0.01
1% 720m	8.47%	238.0min	0.59
0.05% 180m	10.61%	71.0min	0.05
0.05% 720m	23.41%	168.0min	0.72

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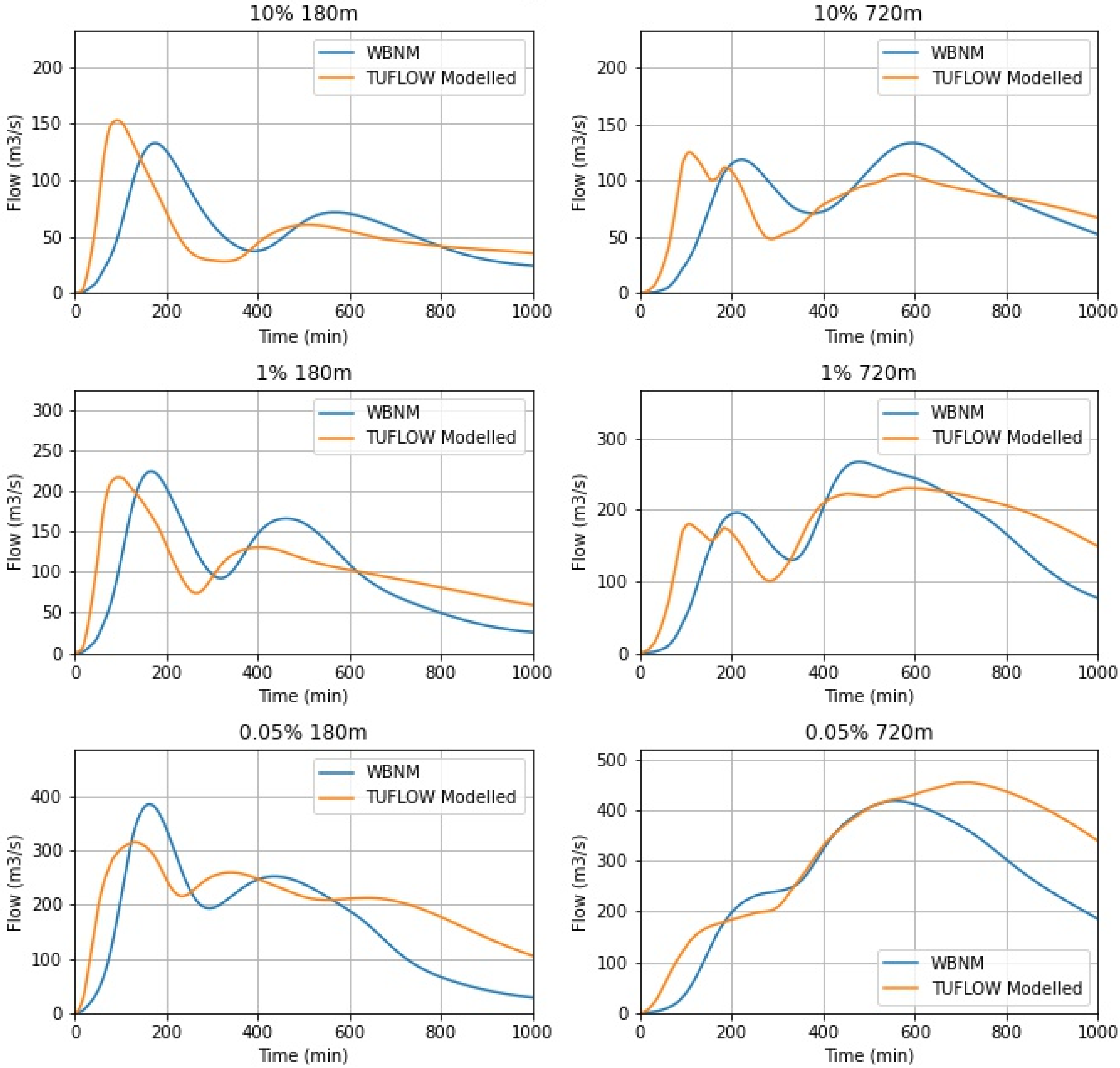
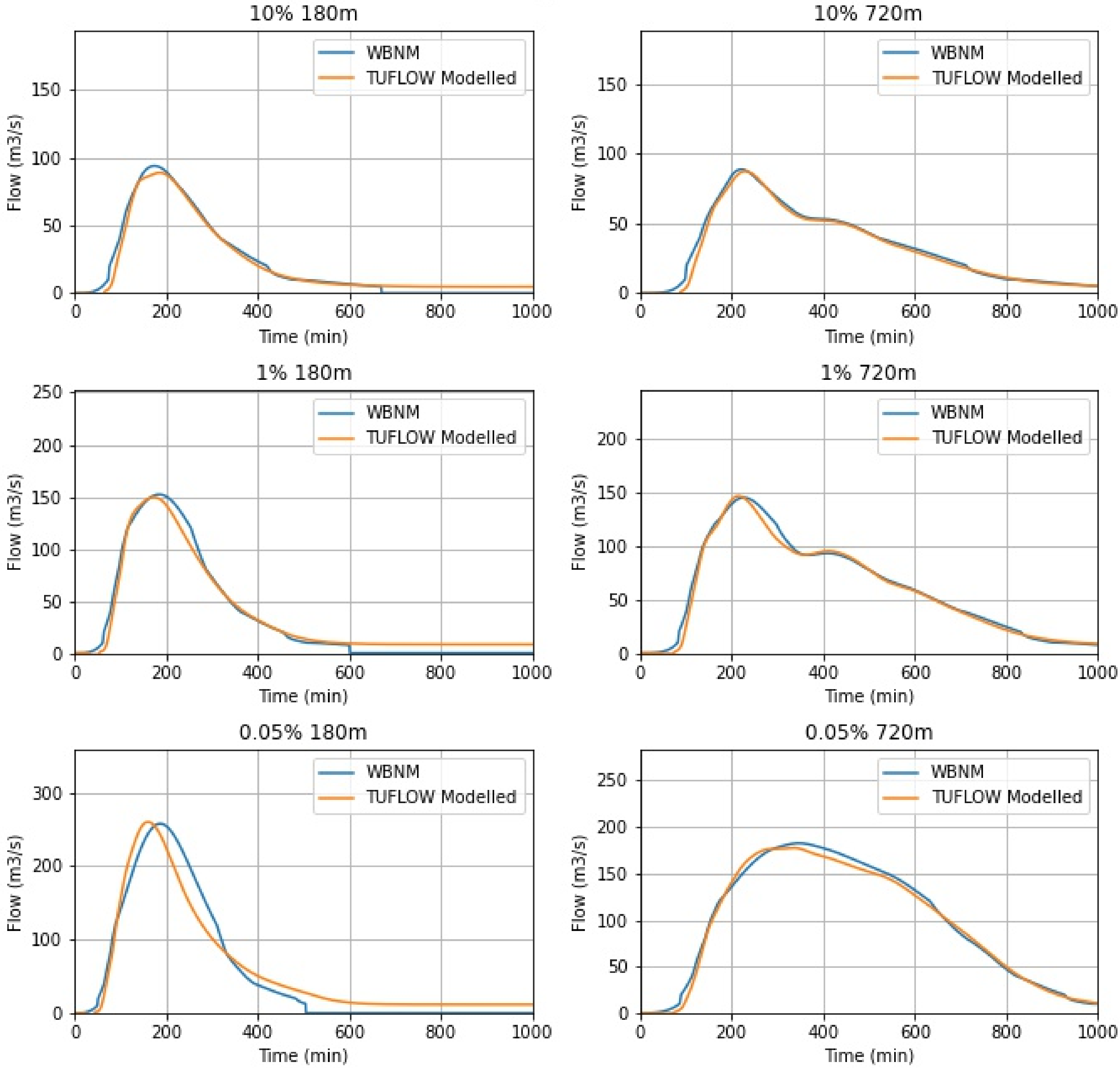
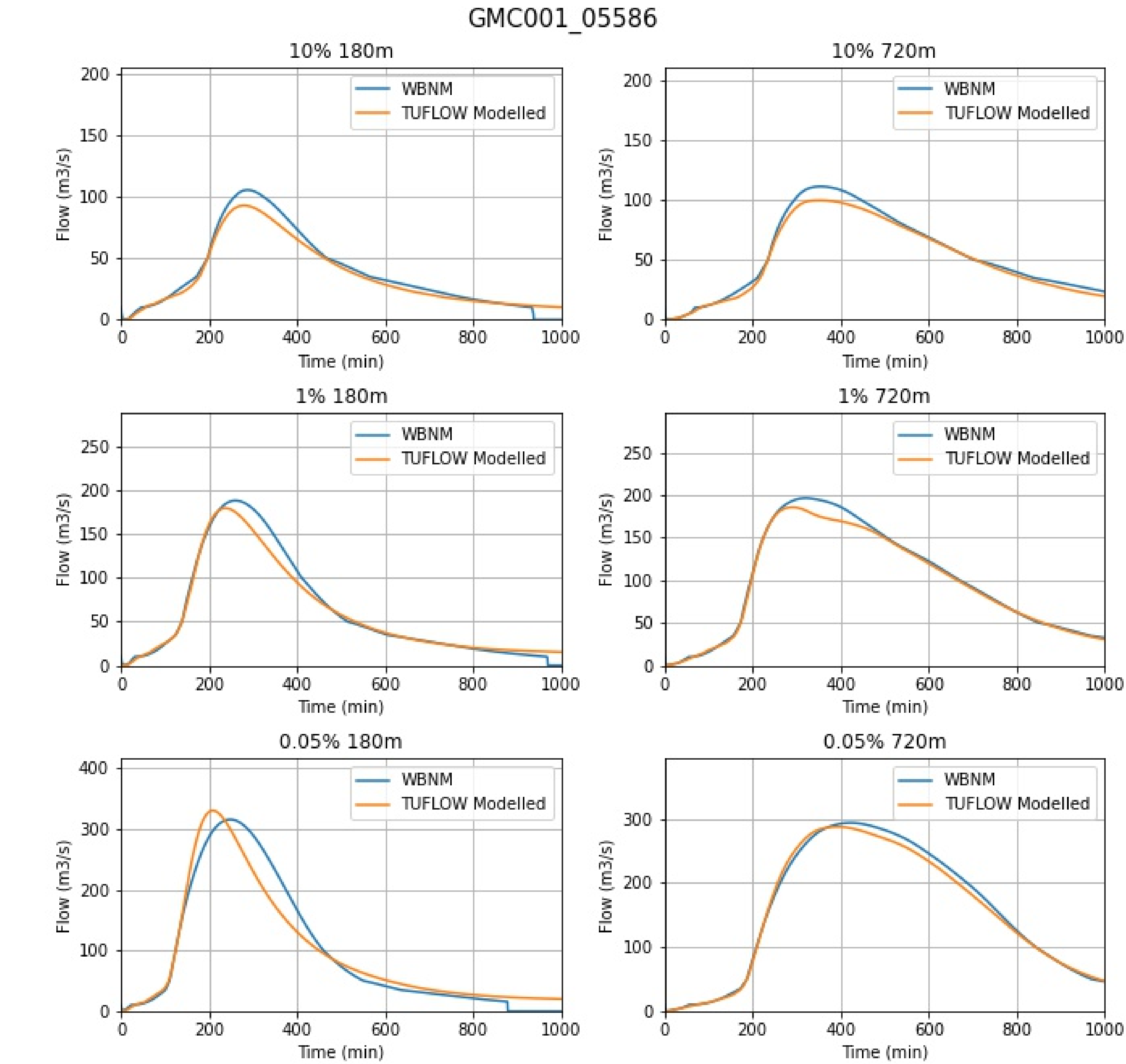


	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	15.32%	83.0min	-0.14
10% 720m	6.09%	487.0min	-0.33
1% 180m	3.2%	72.0min	-0.19
1% 720m	13.65%	107.0min	0.28
0.05% 180m	18.12%	31.0min	-0.09
0.05% 720m	8.67%	160.0min	0.65

GMC001_10647

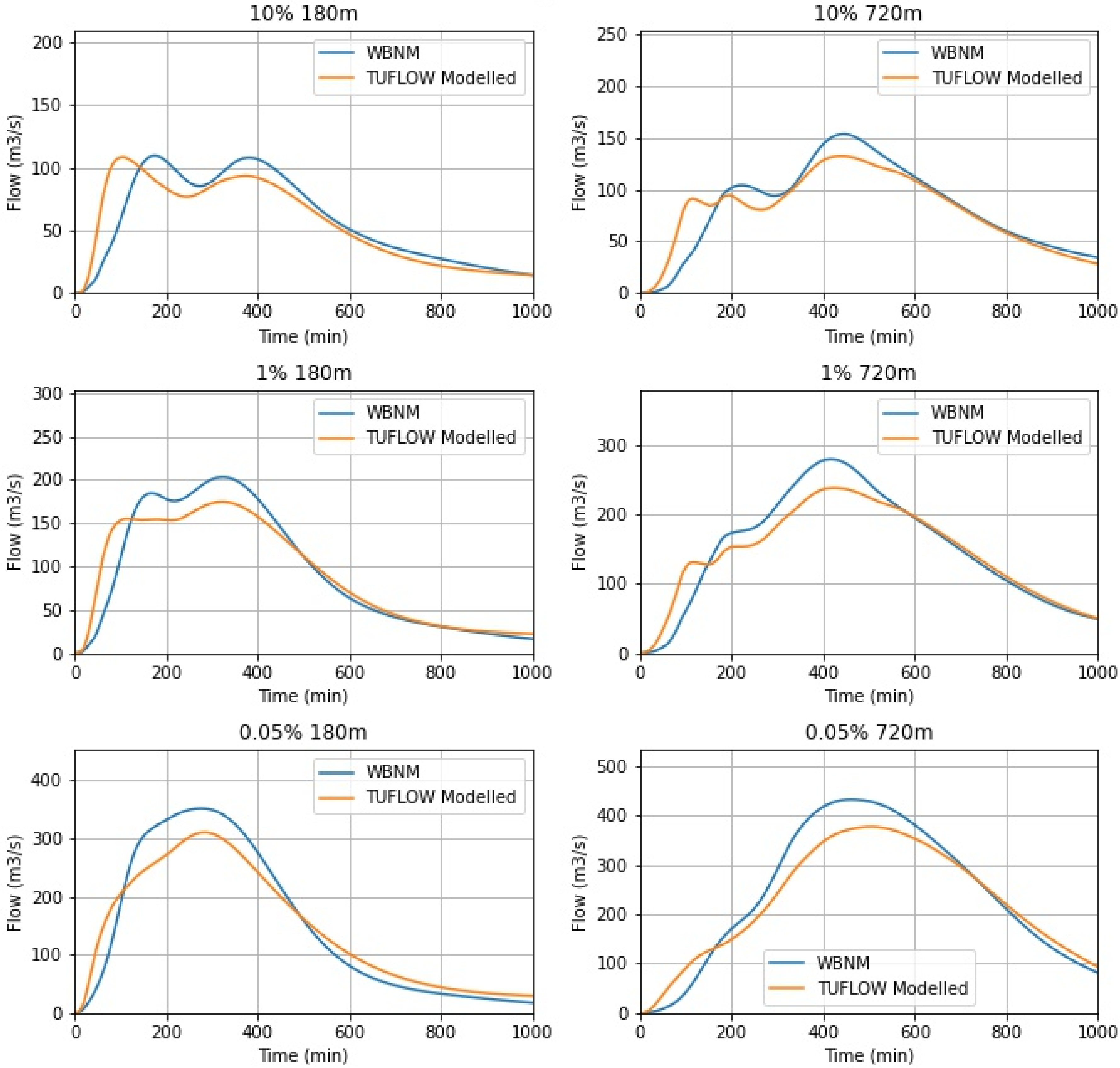


	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	5.39%	12.0min	0.98
10% 720m	1.61%	9.0min	0.99
1% 180m	1.75%	13.0min	0.97
1% 720m	1.01%	12.0min	0.99
0.05% 180m	0.92%	27.0min	0.93
0.05% 720m	2.72%	11.0min	0.99



	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	11.99%	8.0min	0.95
10% 720m	10.4%	2.0min	0.97
1% 180m	4.62%	23.0min	0.97
1% 720m	5.51%	31.0min	0.99
0.05% 180m	4.67%	40.0min	0.93
0.05% 720m	2.17%	26.0min	0.99

GMC001_00319



	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	1.0%	69.0min	0.74
10% 720m	13.88%	6.0min	0.8
1% 180m	14.1%	0.0min	0.87
1% 720m	14.72%	7.0min	0.86
0.05% 180m	11.73%	9.0min	0.89
0.05% 720m	12.73%	45.0min	0.89

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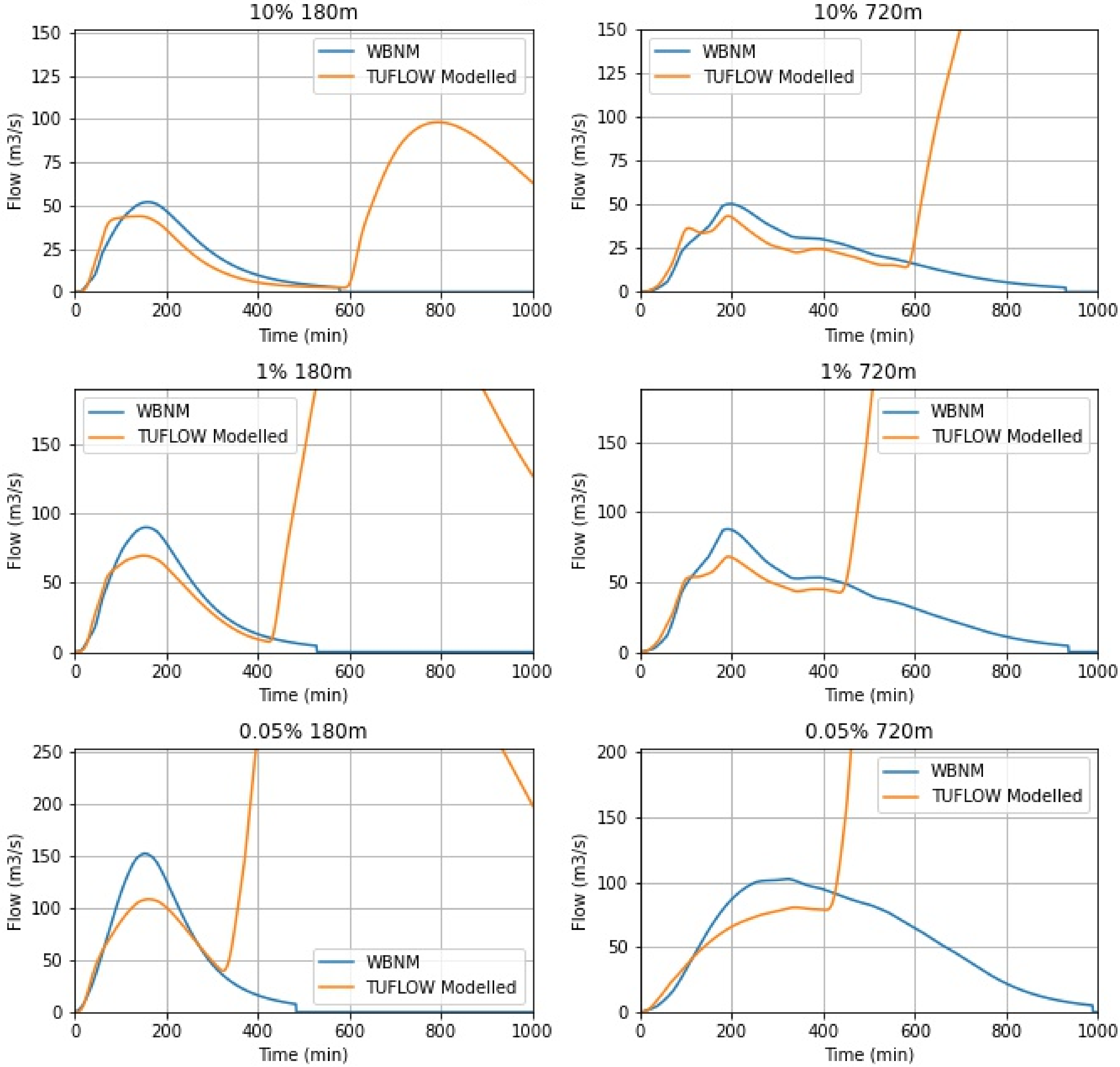
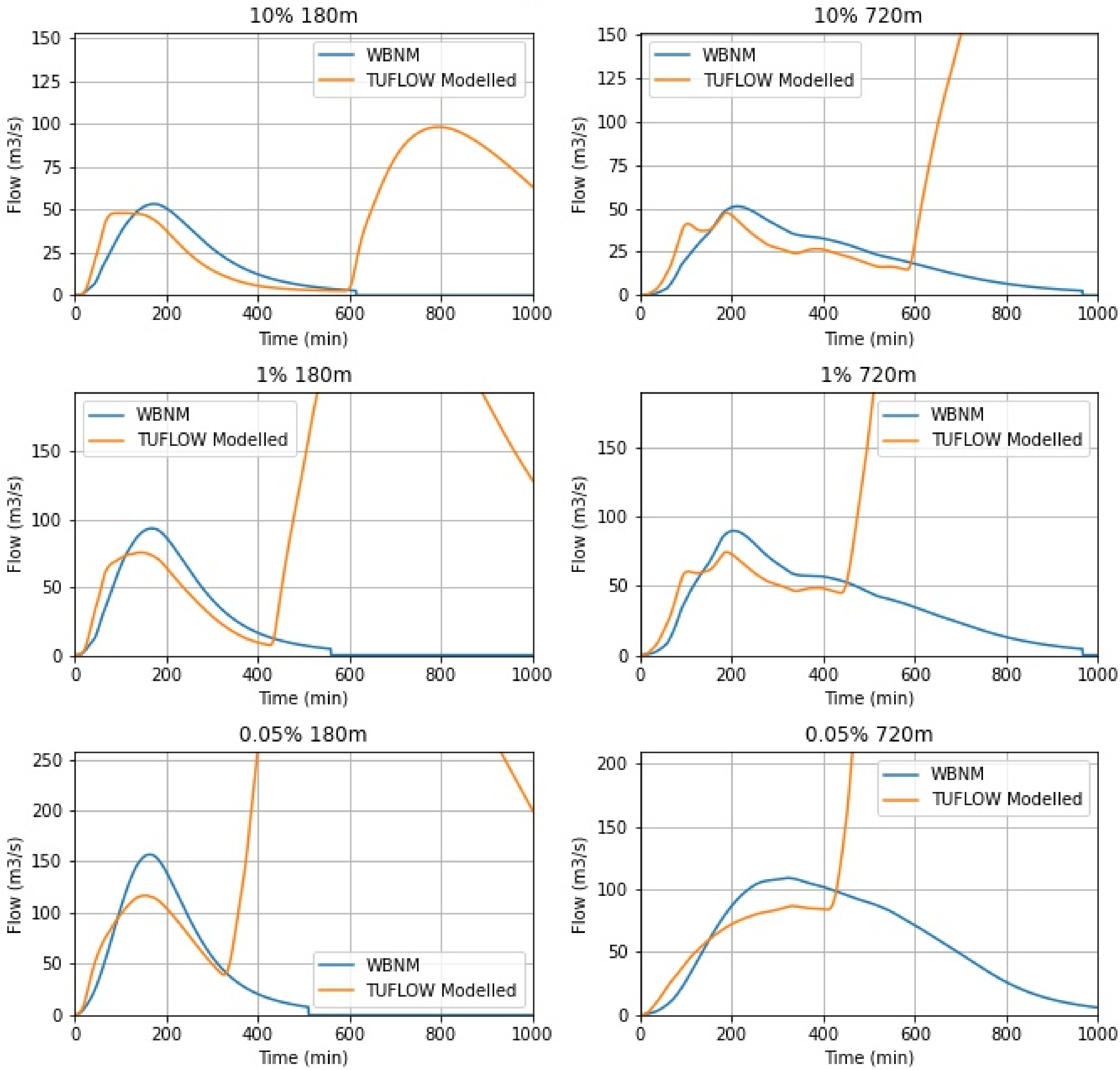


	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	88.87%	633.0min	-0.28
10% 720m	322.57%	648.0min	-0.17
1% 180m	222.0%	505.0min	-0.17
1% 720m	388.61%	519.0min	-0.1
0.05% 180m	236.3%	392.0min	-0.15
0.05% 720m	564.25%	391.0min	-0.06

ELI011_00000



	Peak diff (%)	Peak timing diff (min)	NSE
10% 180m	84.35%	622.0min	-0.3
10% 720m	315.57%	635.0min	-0.17
1% 180m	211.98%	497.0min	-0.18
1% 720m	374.17%	510.0min	-0.1
0.05% 180m	219.97%	391.0min	-0.15
0.05% 720m	495.94%	397.0min	-0.06

APPENDIX D
BMT HEH METHODOLOGY MEMORANDUM

BMT Commercial Australia Pty Ltd
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ABN: 54 010 830 421

Draft Technical Note

Project	A11567 – RFD 2021 Major Update		
From:	Blair Filer, Richard Sharpe, Anne Kolega		
Date:	22/08/2022	To:	Hester van Zijl, MBRC Tyrone Attard, MBRC Alana Mosely, MBRC
Doc Ref:	T.A11567.005		
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 2021 Major Update. This methodology is, in general, very similar to the method developed by Moreton Bay Region Council (Council), and which was provided as part of the study brief. However, the slightly amended methodology offers considerable efficiencies over the original approach when creating the HEH models. This in turn will be less time consuming and therefore advantageous to the overall project.

It should be noted that BMT has undertaken initial testing of the amended HEH methodology using the BCC catchment and the results of this testing were provided to Council on 4 July 2022. These results were very encouraging, however additional fine tuning of this methodology may be required as the project evolves.

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 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 Task B of 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.

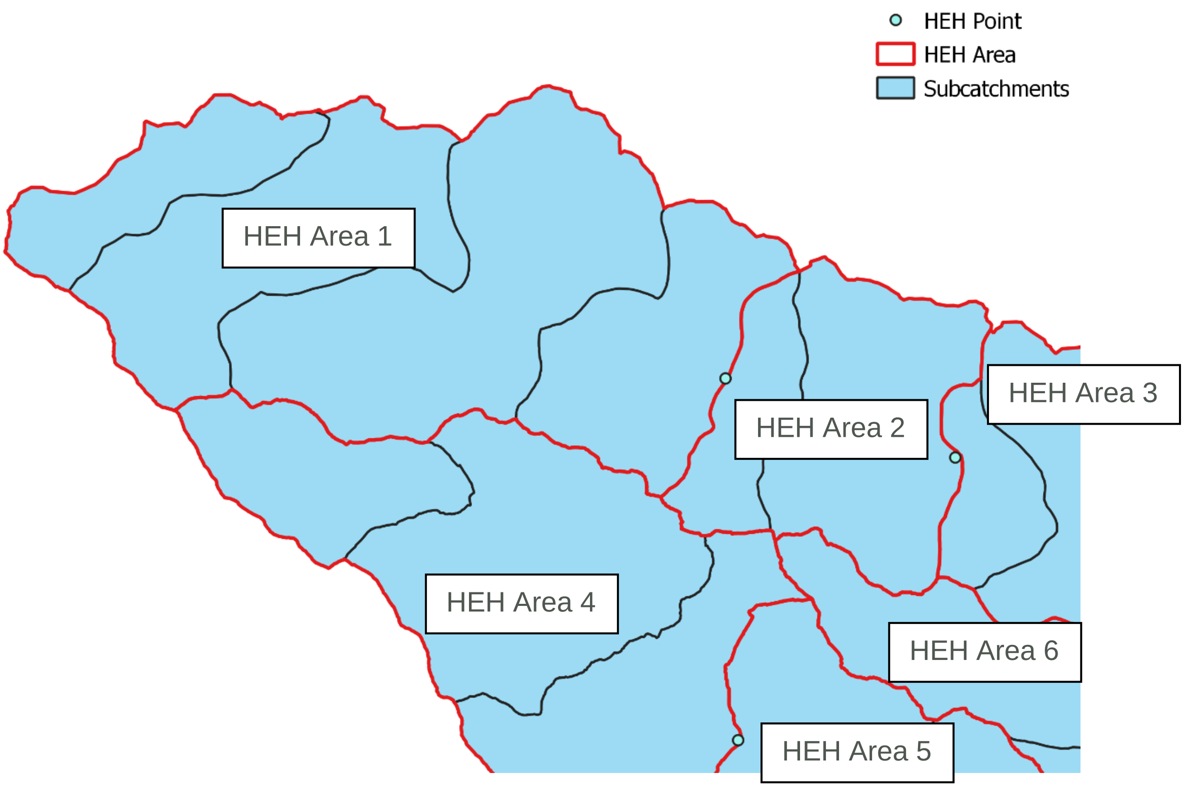


Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

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[1]. 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[2]. 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.

---

[1] ARR1987 splits temporal patterns into two ARI buckets (above and below the 30-year ARI)
[2] 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).

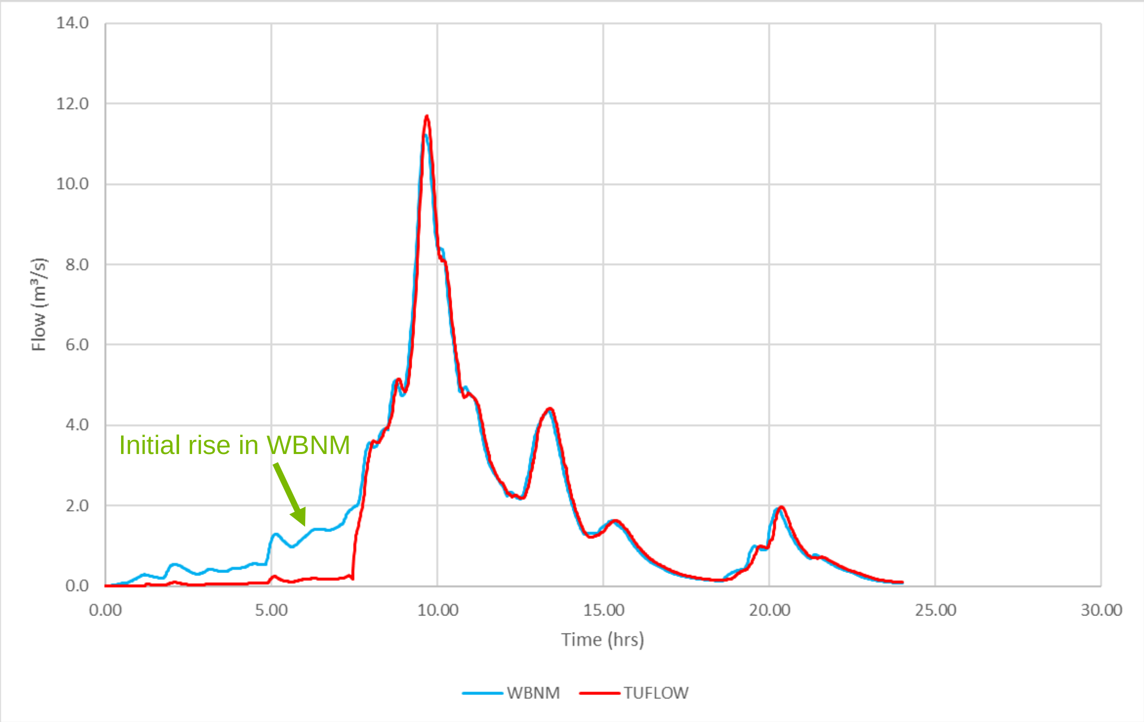


Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

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[3]. 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).

[3] 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

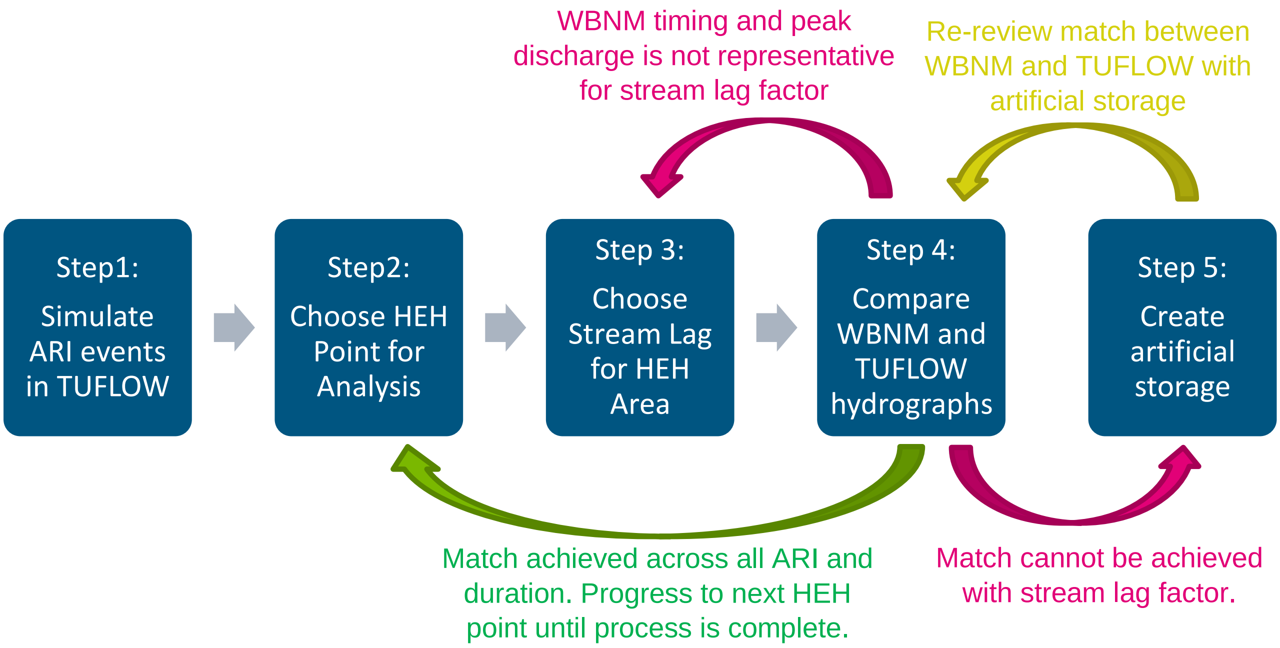


Figure 1.3 Flow chart for the HEH model methodology

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.

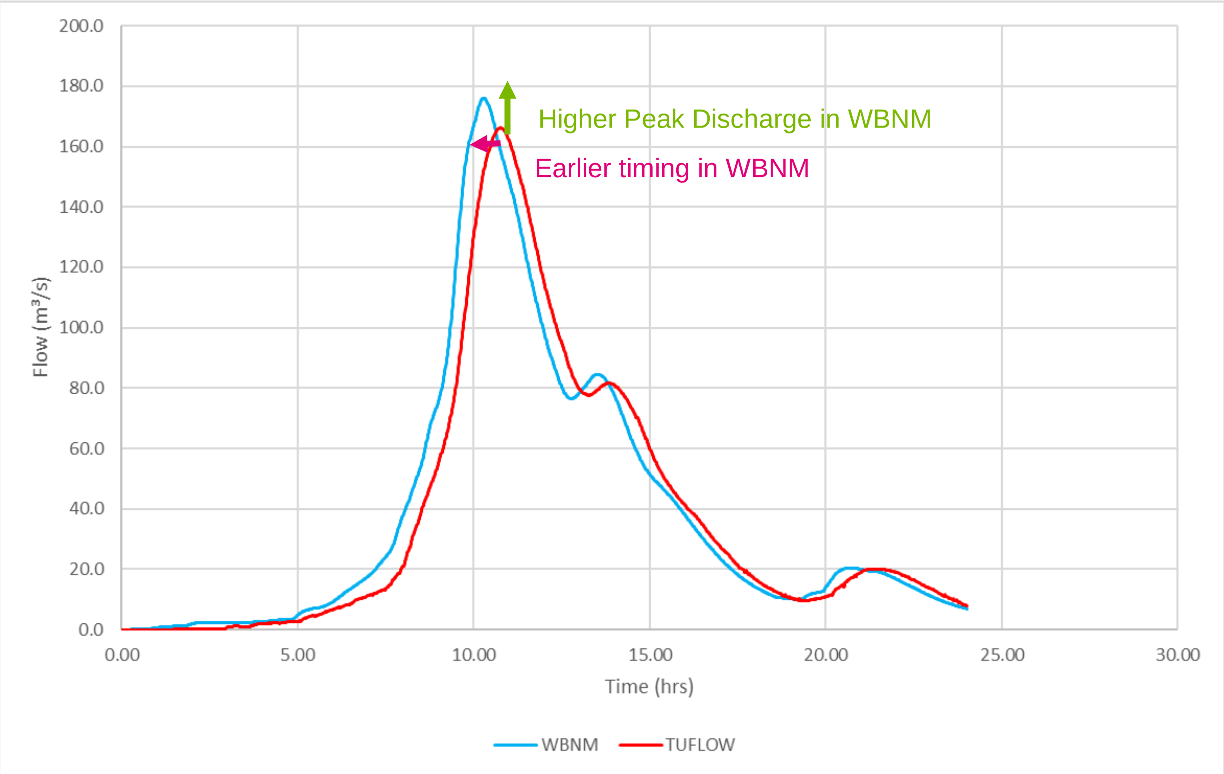


Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

Step 5: Create an artificial storage

Note: This step is based on averaging 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 during implementation.

To develop an artificial storage for the WBNM model, a table of water levels (H), the storages (S), and outflows (Q) is required. The development of the table is in two stages, a S-Q curve and a H-Q curve. The S-Q curve requires calculations of storage at each timestep, and the H-Q curve is the development of a rating curve from the TUFLOW results.

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

Develop the Storage-Outflow table

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

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

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

Step 5.1 Calculate the storage at each timestep

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

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

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

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

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 = **60s**

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

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

S_t = 1/2 x 60s ($8.3m^3/s$ - $7.9m^3/s$) + $1485m^3$ = **$1497m^3$**

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[4]. 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).

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

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

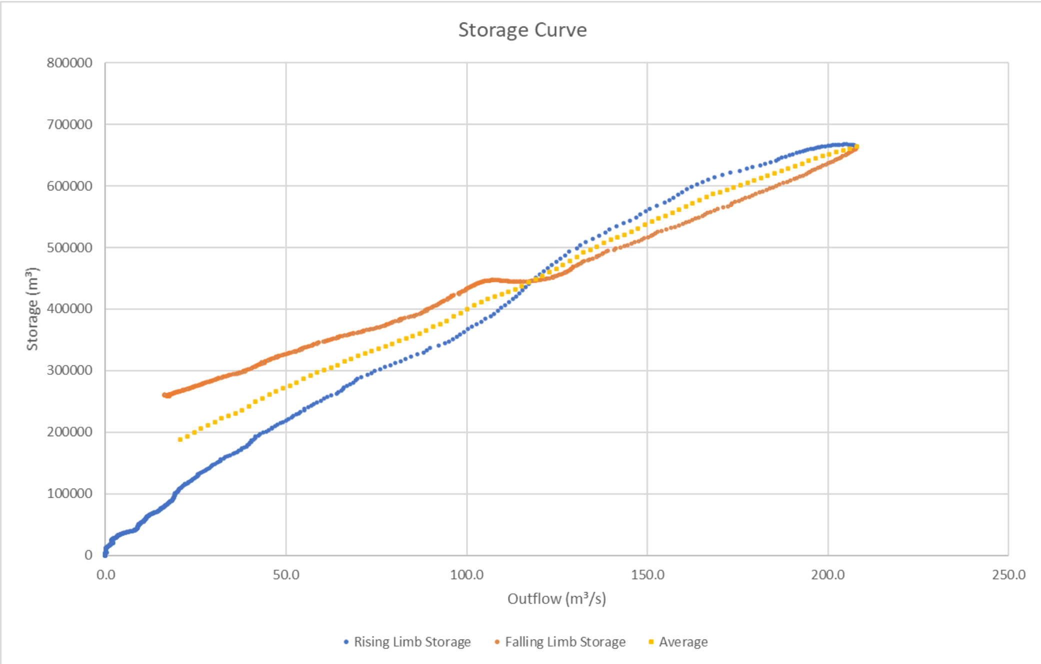


Figure 1.6 Ideal Storage-Outflow Curve

Light green dots result in
a curve which is not ideal

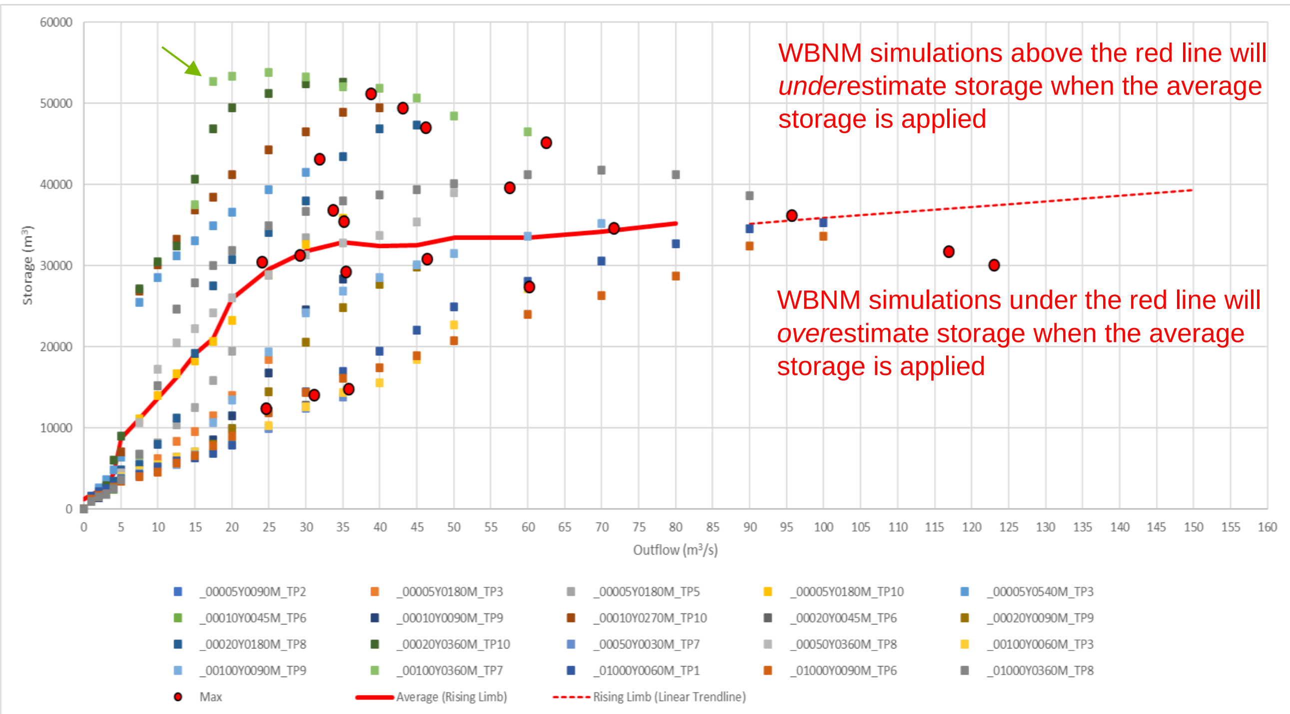


Figure 1.7 Example of an averaged S-Q curve (storages extracted from the rising limb of each duration and ARI)

Develop the HSQ rating curve

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.

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.

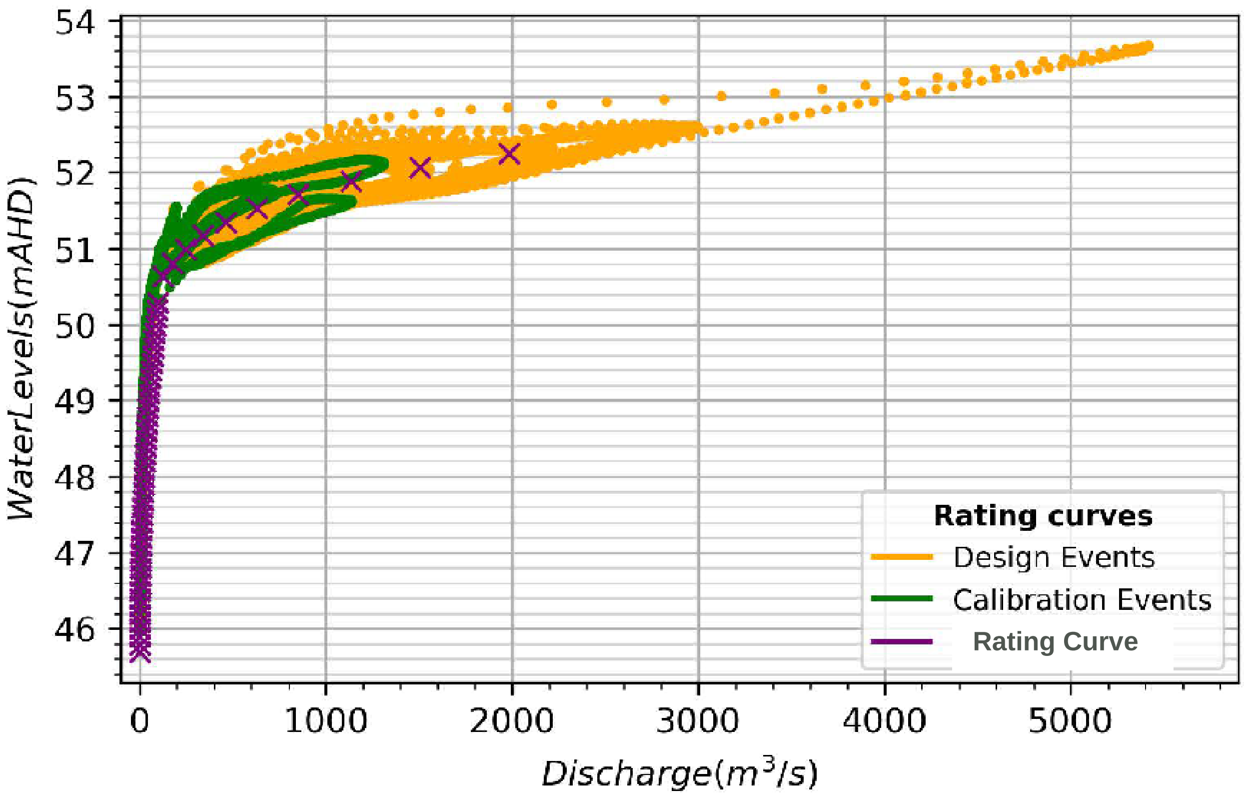


Figure 1.8 Rating curve with hysteresis

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 from the rating curve
SURFACE_AREA	0
STORAGE_FACTOR	1

APPENDIX E
WATER TECHNOLOGY TASK E MEMORANDUM

MEMORANDUM

To	Bonnie Beare
From	Andrew Thompson
Date	31 October 2022
Subject	Task E – Pumicestone Joint Calibration and Validation
Our ref	22020122_PUM_M03_V01.docx

1 INTRODUCTION

This memorandum outlines the methodology and results for the Joint Calibration and Validation of the WBNM and TUFLOW models for the Pumicestone (PUM) catchments. This package of work represents our submission for Task E and engages the subsequent hold point for Council to review the results of the model calibration. We acknowledge Councils intimate local knowledge of these catchments, and we welcome feedback to the provided results.

2 DATA AVAILABLE

Stream and rainfall gauge data for the Pumicestone study area was supplied by MBRC for use in this assessment. The location of these gauges, in relation to the PUM TUFLOW model extent, is presented in Figure 2-1. As evident from this figure, there is limited rainfall and stream gauging data within the study area.

2.1 Stream Gauge Data

There are two (2) stream gauges located within the Pumicestone study area, the details of which are outlined in Table 2-1.

Table 2-1 Stream Gauges Used for Validation

Gauge Name	ID	Event Availability
Elimbah (Rose Creek Rd) Alert	540543	March 2012 - Present
Toorbul (Donnybrook Rd) Alert	540635	May 2013 - Present

2.2 Rainfall Data

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

Table 2-2 Rainfall Gauges Used for Validation

Gauge Name	ID	Event Availability
Elimbah (Rose Creek Rd) Alert	540543	April 2012 - Present
Toorbul (Donnybrook Rd) Alert	540635	December 2013 - Present
Wamuran (McClintock Rd) Alert	540652	October 2013 - Present
Elimbah (Eaton Rd) Alert	540653	October 2013 - Present

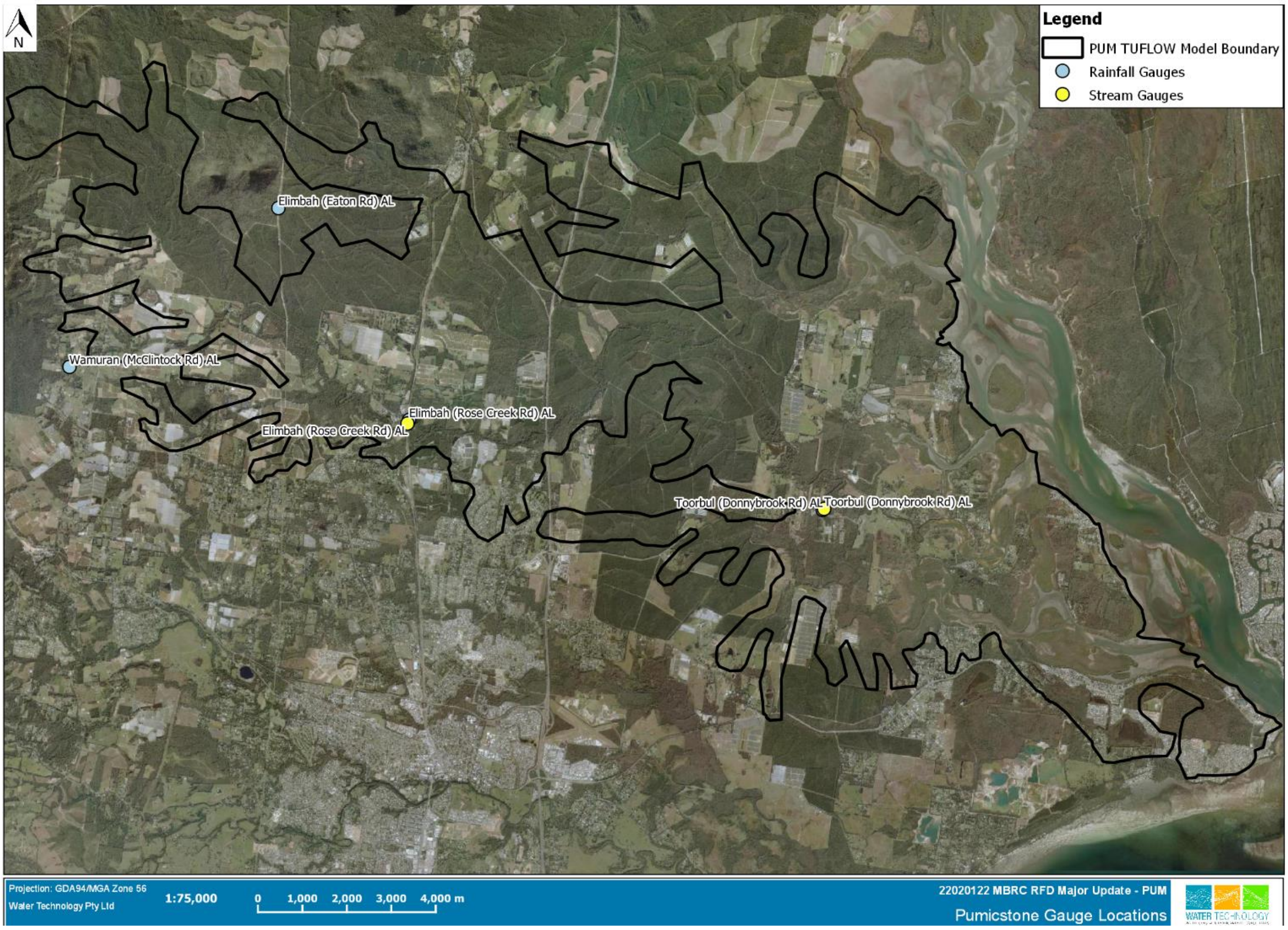


Figure 2-1 Rainfall and Stream Gauge Locations

2.3 Flood Debris Marks

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 2-3 summarises the number of debris marks available for the respective catchments and events. It is noted that some debris marks were captured outside of the modelled flood extent and are most likely attributed to overland flow rather than the intent of the model which is flooding from creeks and waterways.

Table 2-3 Debris mark availability summary

Event	# of Debris Marks	# of Debris Marks in TUFLOW model extent
February 2015	8	7
May 2015	16	12
February 2022	96	81

3 HYDROLOGICAL MODELLING

3.1 Rainfall Application

Hydrological data from the rainfall stations outlined in Table 2-2 were utilised to generate the spatial distribution of rainfall in the February and May 2015 and February 2022 events. Rainfall was distributed using the standard WBNM approach which assigns rainfall depths to each sub-area 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.

3.2 Losses and Catchment Parameter

Table 3-1 presents the adopted Initial and Continuing Loss values for the respective validation events across the study area. 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 3-1 Validation events - WBNM adopted parameters

Event	Catchment Lag Parameter	Initial Loss (mm)	Continuing Loss (mm/hr)
February 2015	1.6	20	2.5
May 2015	1.6	20	2.5
2022	1.6	20	2.5

4 HYDRAULIC MODELLING

4.1 Updates

Appendix A provides responses to Council's model review comments for both models. The updated models have been utilised for the validation process. It is noted that the works and landforms associated with the Bruce Highway upgrade were removed from the calibration models to better represent ground conditions during the calibration events.

4.2 Hydraulic Roughness

Amendment of Manning's 'n' values has been undertaken at the request of MBRC. Of particular note is the use of the High Density Vegetation Class, with Class 1 and Class 2 supplied for use in the BCR and PUM models. Further discussion regarding the use of these classes and the varying results is provided in detail in the following section.

5 CALIBRATION AND VALIDATION RESULTS

5.1 Overview

The hydraulic model was calibrated and validated to three (3) historical events (February 2015, May 2015 and February 2022). Initial testing using the High Density Vegetation Class 2 roughness resulted in water levels significantly higher than the recorded water levels for all three (3) historical events. As such, the High Density Vegetation Class 1 roughness values were adopted for the PUM model which proved to be particularly good when validating the model to the February 2022 and February 2015 flood events but still high for the May 2015 flood event. Initial losses in the hydrologic model for the May 2015 events were adjusted from 20 IL to 40IL to account for this increase. A summary of the validation is outlined in the following sections.

5.2 February 2015

Figure 5-1 and Figure 5-2 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the February 2015 flood event. As confirmed by MBRC, the water level data record for this event at the Elimbah (Rose Creek Road) Alert gauge appears to be flawed and incomplete as shown in Figure 5-1. As such, this dataset cannot be utilised for the validation of the February 2015 model at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-2, provides a better relationship with a peak modelled level of 3.66 mAHD compared to a recorded height of 3.45 mAHD.

Figure 5-3 shows the histogram and the spatial map of the hydraulic model validation when comparing the TUFLOW model results to the surveyed flood heights. The February 2015 event has limited data with only 7 marks to compare however 5 of the marks were within 200 mm difference compared to the recorded levels. As such, the hydraulic model has performed reasonably well in matching the observed flood marks for the February 2015 flood event. A map showing the spatial location of the debris marks for the February 2015 event, overlaid with the peak flood depth, is presented in Appendix B.

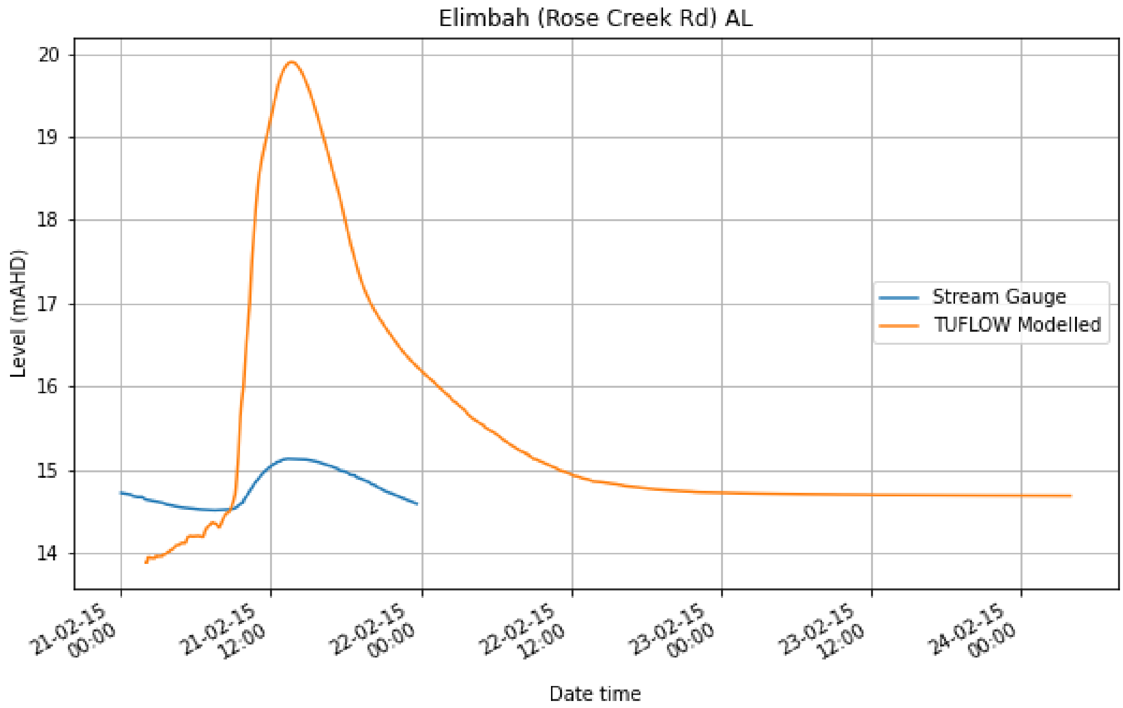


Figure 5-1 February 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

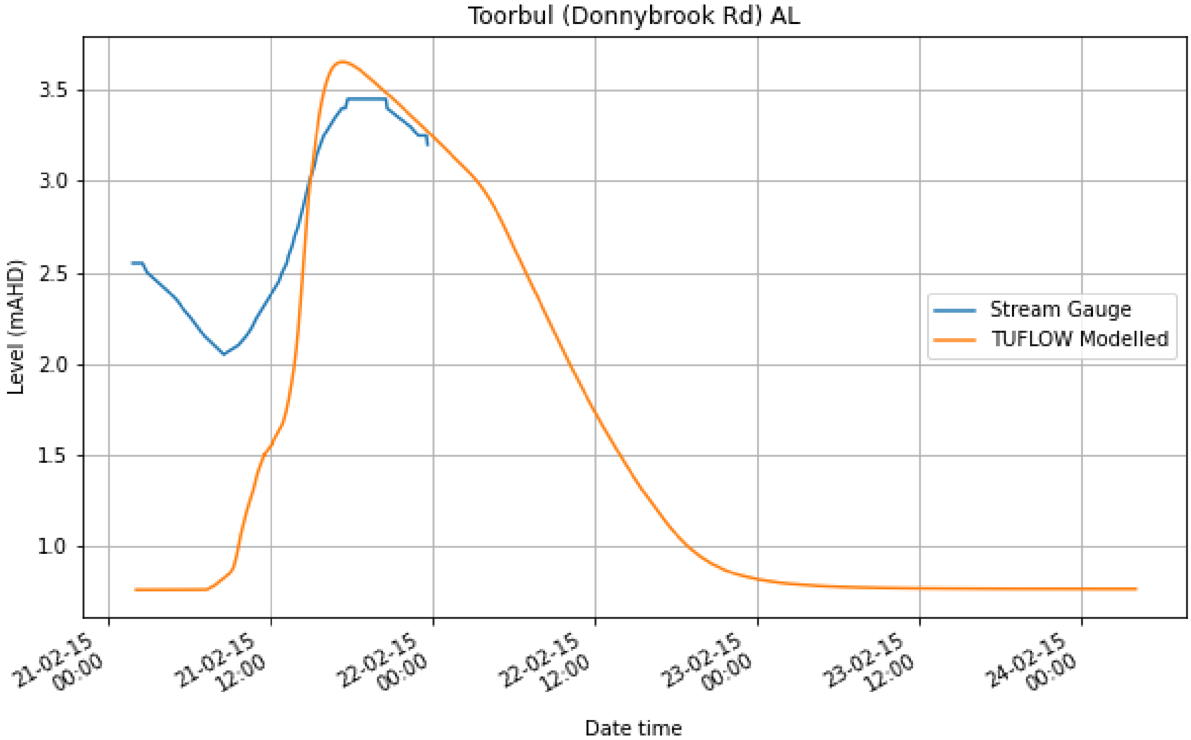


Figure 5-2 February 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

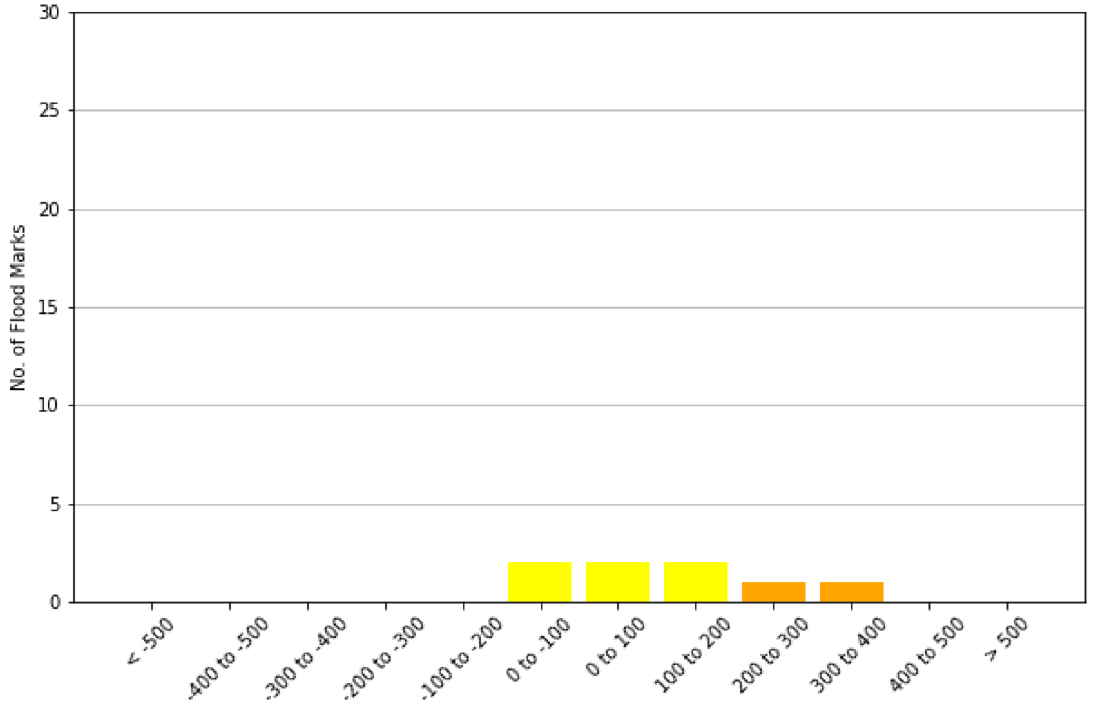


Figure 5-3 February 2015 Debris Histogram

5.3 May 2015

Figure 5-4 and Figure 5-5 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the May 2015 flood event. As confirmed by MBRC, the water level data record for this event at the Elimbah (Rose Creek Road) Alert gauge appears to be flawed and incomplete as shown in Figure 5-4. As such, this dataset cannot be utilised for the validation of the May 2015 model at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-5, provides a better relationship with a peak modelled level of 4.075 mAHD compared to a recorded height of 3.70 mAHD.

Figure 5-6 shows the histogram and the spatial map of the hydraulic model validation when comparing the TUFLOW model results to the surveyed flood heights. The May 2015 event has limited data with only 12 marks to compare. It is noted that there does not appear to be a good relationship between the measured debris heights and the modelled peak water levels. Debris marks where the comparison was less than 200 mm occurred in isolated reaches of the system which indicates that there could be discrepancies with the debris mark data set.

A map showing the spatial location of the debris marks for the May 2015 event, overlaid with the peak flood depth, is presented in Appendix B

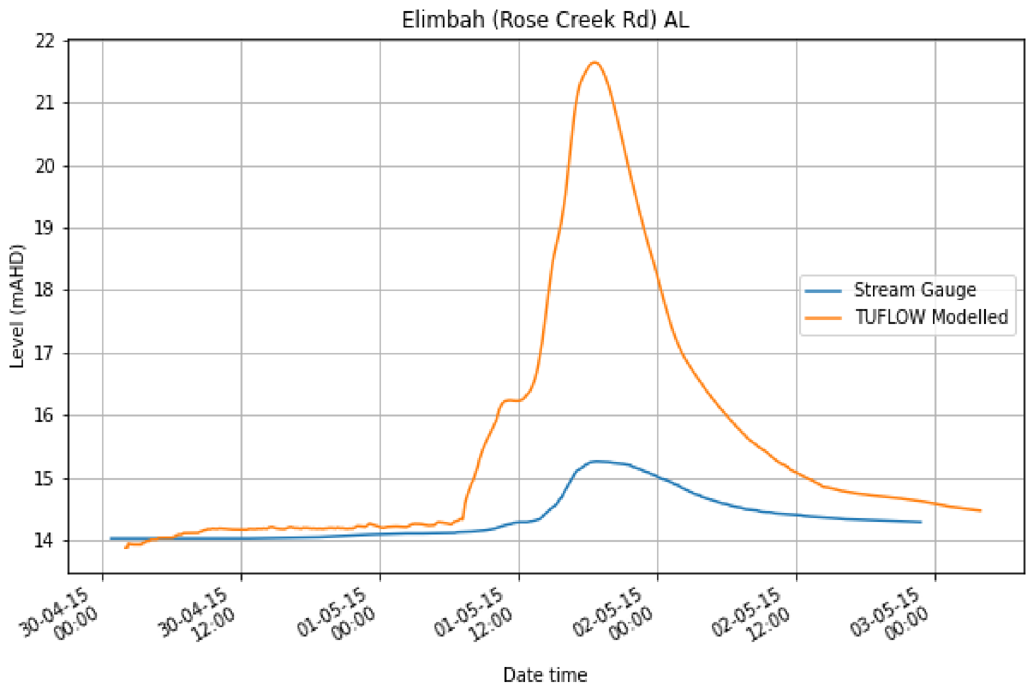


Figure 5-4 May 2015 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

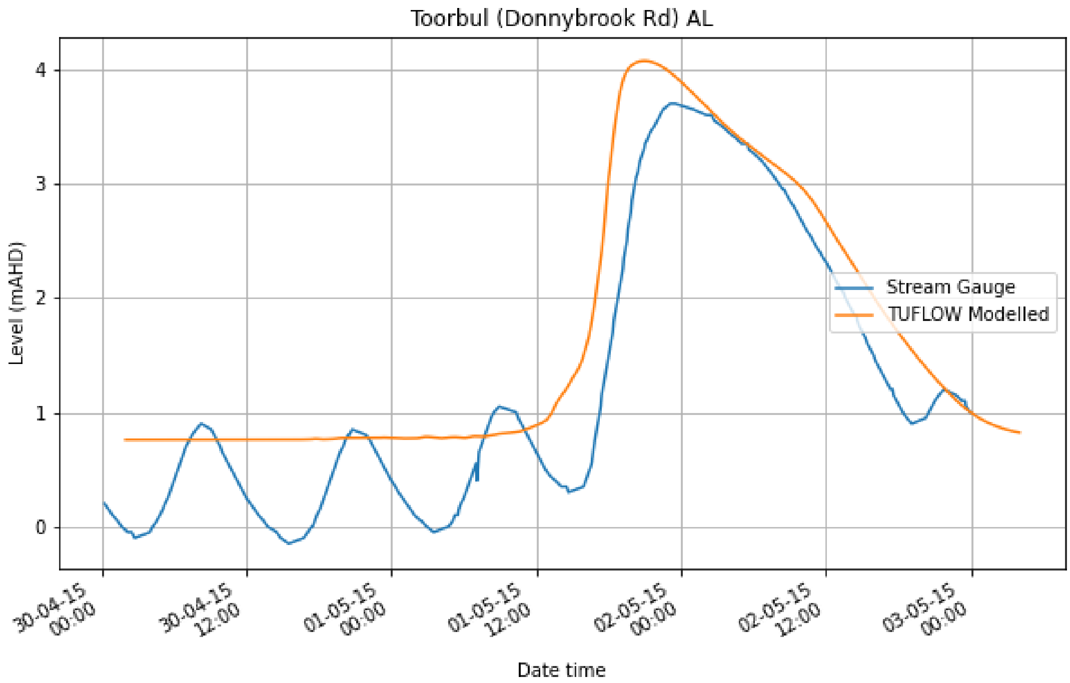


Figure 5-5 May 2015 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

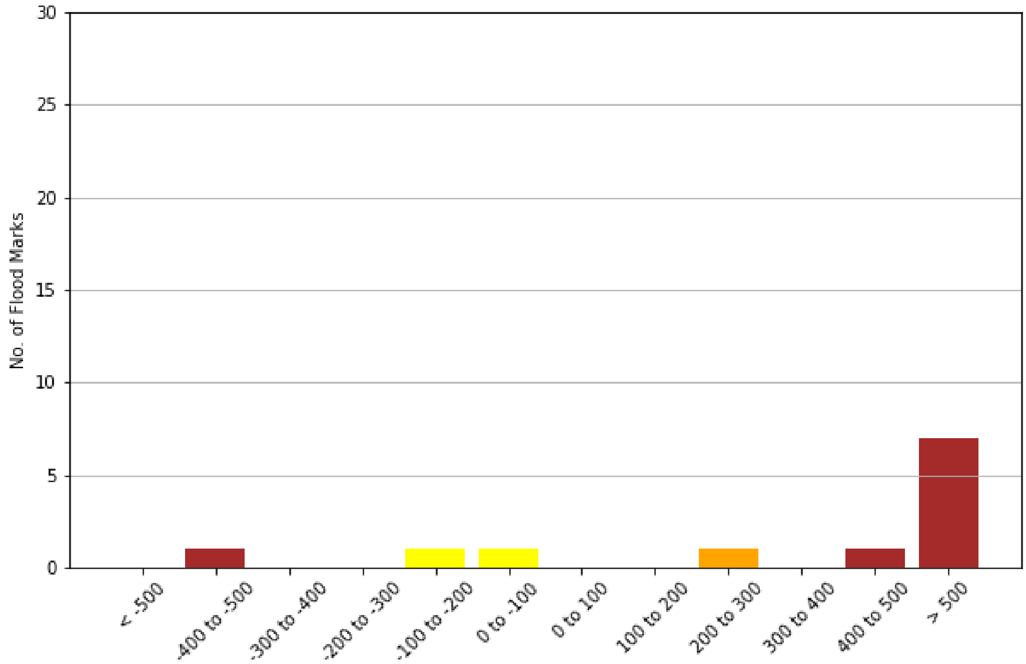


Figure 5-6 May 2015 Debris Histogram

5.4 February 2022

Figure 5-7 and Figure 5-8 shows the comparison of water level hydrographs at the two (2) stream gauges located within the PUM study area with the TUFLOW model plot outputs for the February 2022 flood event. As shown in Figure 5-7, the modelled water levels provide a good comparison to the recorded water level at the Elimbah (Rose Creek Road) Alert gauge with a peak modelled level of 21.763 mAHD compared to a recorded height of 21.79 mAHD. The timing and shape of the modelled water level hydrograph confirms that an excellent representation of the February 2022 event has been replicated at this location. The comparison water level at the Toorbul (Donnybrook Road) Alert, as shown in Figure 5-8 provides a similar result with a peak modelled level of 4.115 mAHD compared to a recorded height of 4.20 mAHD.

Figure 5-9 shows the histogram and the spatial map of the hydraulic model validation when comparing the TUFLOW model results to the surveyed flood heights. There is extensive debris mark data for the February 2022 flood event and the modelled levels compare well. Of the 81 debris marks analysed, 35 marks (43%) have a modelled level of +/- 200mm when compared to the recorded heights. 20 marks (25%) have a comparison of +/- 100mm when compared to the recorded heights. As such, the TUFLOW model for the February 2022 flood event provides an exceptional representation of the February 2022 historical flood event.

A map showing the spatial location of the debris marks for the February 2022 event, overlaid with the peak flood depth, is presented in Appendix B

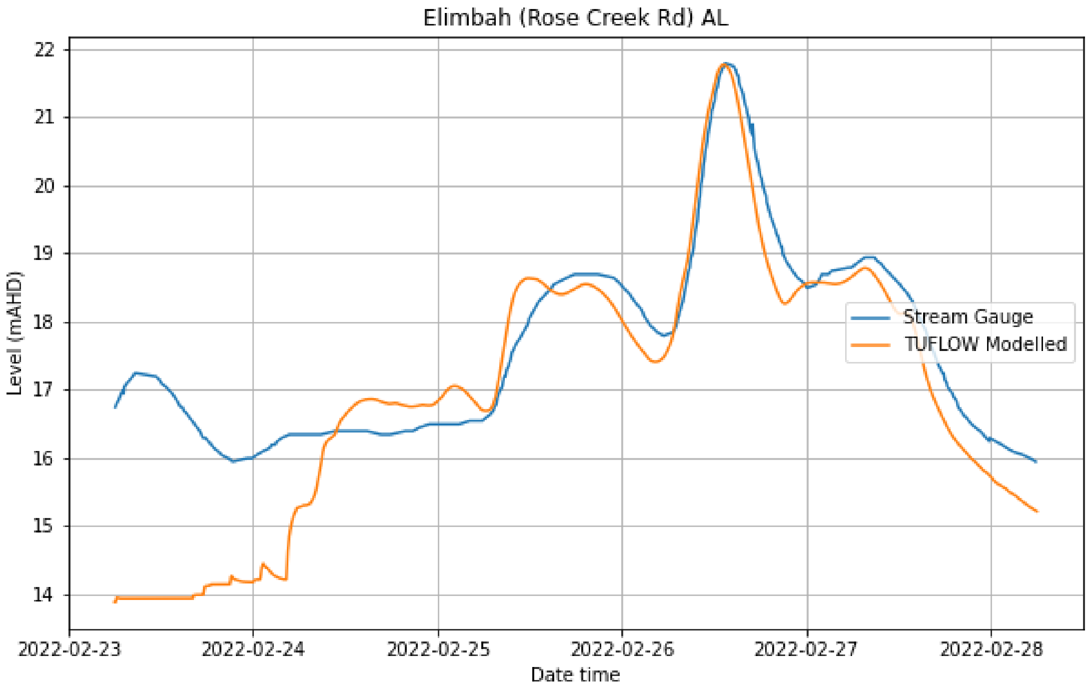


Figure 5-7 February 2022 Flood Event – Recorded v Modelled @ Elimbah (Rose Creek Road) Alert

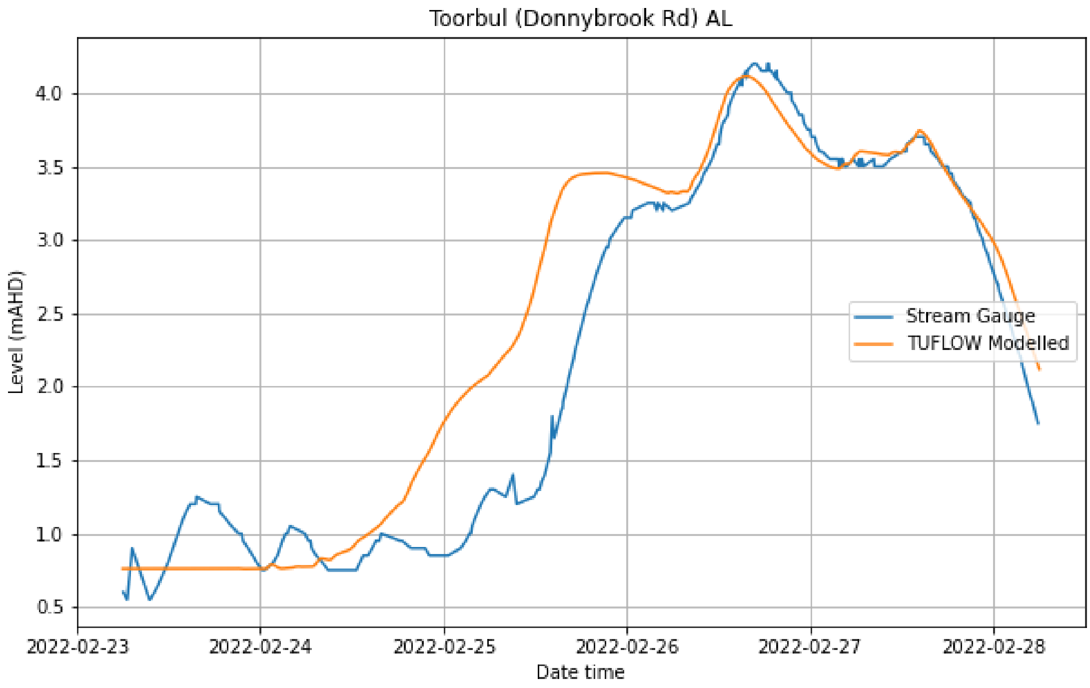


Figure 5-8 February 2022 Flood Event – Recorded v Modelled @ Toorbul (Donnybrook Road) Alert

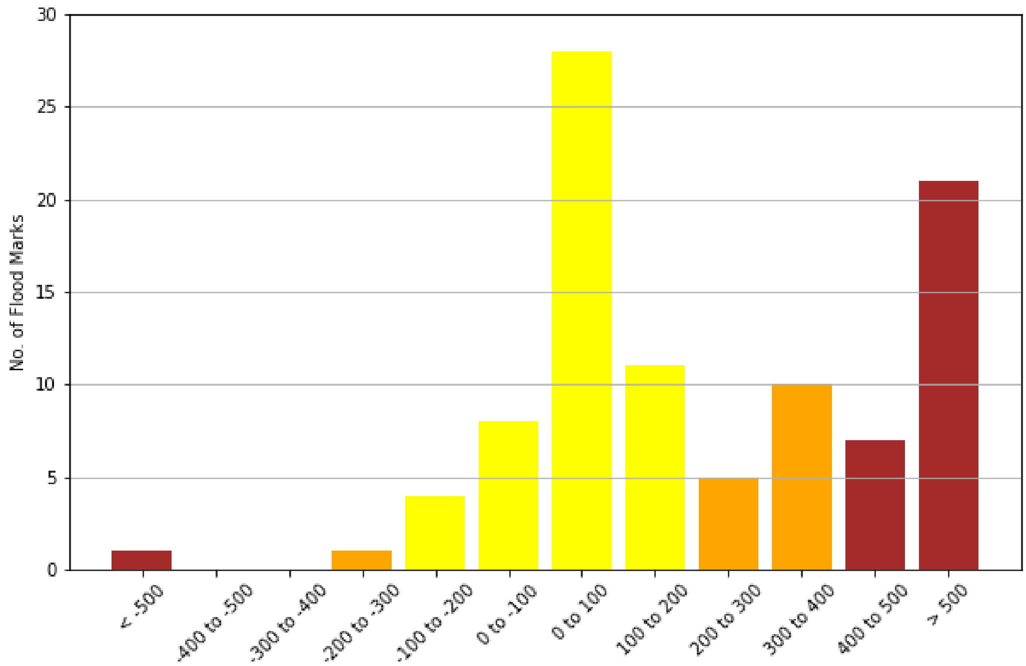


Figure 5-9 February 2022 Debris Histogram

6 SUMMARY

The joint calibration and validation methodology and results provided within this memo has improved the confidence of the modelling outputs throughout the Pumicestone study area. Specifically, through comparison of modelled peak levels and measured debris marks there is increased confidence in both the hydrologic and hydraulic model parameters adopted.

The Pumicestone model was validated to three (3) historical events (February 2015, May 2015 and February 2022). Initial testing, which resulted in significantly higher levels in the model for both events, facilitated the adjustment of the hydrologic model to include a higher initial loss (40 mm) for the May 2015 event and the adoption of the High Density Vegetation Class 1 roughness values for all three events in an attempt to achieve a better comparison. The February and May 2015 validation was limited as the supplied recorded water level data at the central gauge within the study area (Elimbah (Rose Creek Road) Alert) contained errors. Validation to the downstream gauge (Toorbul (Donnybrook Road) Alert) provided a better comparison in terms of recorded water level for both 2015 events. Similarly, the assessment and comparison of debris mark levels against the modelled results indicates a somewhat acceptable match for the February 2015 event but not a good match for the May 2015 event.

The February 2022 event provided a significantly more robust validation event due to the better gauge data and widespread debris observational marks. The modelled peak water level was found to be 27 mm lower than the recorded level and 85 mm lower than the recorded level at the Elimbah (Rose Creek Road) Alert and Toorbul (Donnybrook Road) Alert gauges, respectively. The model results also showed very encouraging results with approximately 43% of marks within 200 mm and 25% within 100 mm for the February 2022 event.

Overall, the validation events have added significant confidence that the Pumicestone WBNM and TUFLOW models are representing the catchment's hydraulic response and are fit for purpose to progress to the design event phase of the project.

APPENDIX A
COUNCIL MODEL REVIEW COMMENTS

DESIGN DOCUMENTATION (INCLUDING CALCULATIONS) VERIFICATION RECORD

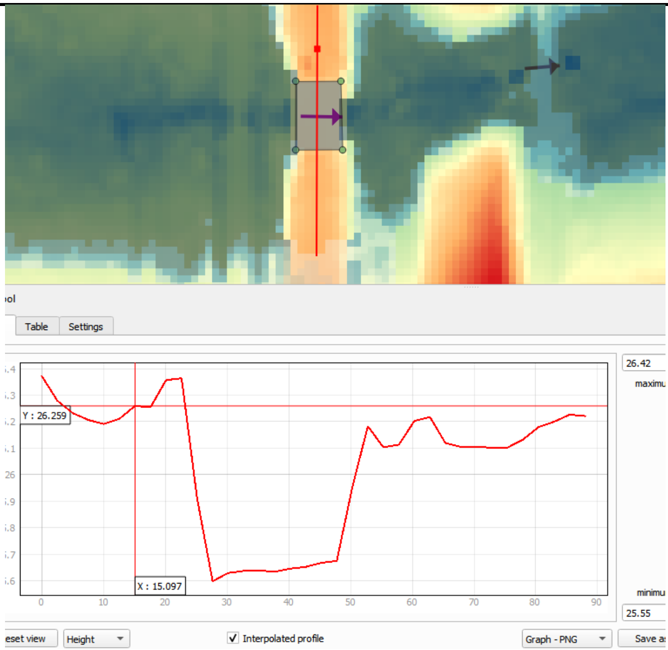
Project Title: RFD Model Update - Pumicestone Model Review   Document Number: Nil

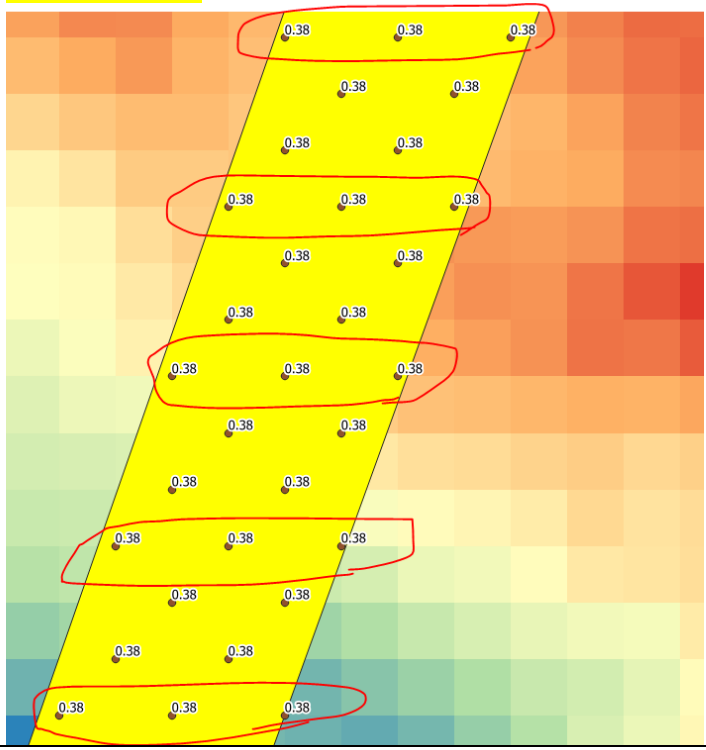
Project discipline: Floodplain Management   Designer: WT   Verifier (Checker): SC (MBRC)

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
General Items			
Supporting Material for this Review:	Please note - there are three shapefiles that have been provided as part of this review which include additional comments and culverts/1d_nwk to add. These are: - Review_Comments.shp - Extra_Culverts_PUM.shp - Extra_1dNetwork_PUM.shp		
Paste tcf here	PUM_R_003a_E_~e1~_~e2~_~s1~_05.tcf		
Naming Convention	To be advised in separate review		
GIS File Format	Format updated to shp format as per brief. GIS files converted from MI format. Model shps combined into single 003a files.		
Hydraulics			
Model Scheme and Engine	Updated to HPC using 2020-10-AB isp TUFLOW version due to model crashing issues in version AC (previously discussed in email). **Recommend adopting latest 2020-10-AD to see if issues have been resolved in this version. If so adopt AD moving forward.**	Latest version of TUFLOW used.	
Hardware: CPU or GPU	GPU		
Viscosity Scheme	Wu viscosity - default for 2020 solver		
Control File Commands - Any specific command lines not reading in files e.g. nodal area defaults etc.	Control file layout seemed neat - good work. If you do note any redundant commands from legacy modelling that are not required, please remove.		

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
- Remove redundant commands			
Run Duration Sufficient to Capture Model Peaks	Only 1% AEP/ 180min currently run, however start/end time specified in tef for each duration. Review with updated hydrology to ensure peaks are captured.		
Outputs Specified Correctly - Time series output duration - Map formats and data output types	Time-series output = every 1mins (unchanged from 002c) Map output interval = every 20mins (unchanged from 002c) **Output timesteps vary between different RFD models - should we be applying consistently - to be discussed in future catchup**	TBC	
PO lines - Reviewed and added lines where warranted at new structures etc	Converted to shp as per brief. Only line POs have been provided, points shp file is not in the TUFLOW directory even though it is included in tcf. **Assuming they are to be included at a later stage?** **Currently no water level (H) POs included. Please include (at minimum where previous 002c model had 'H' POs). This may be part of the missing points PO layer?** Check PO's at bridges to see if done correctly	POs were added to the model but issues in outputting of results occurred. MBRC have provided updated PO file with additional reporting points.	
Cell Size	5m (unchanged from 002c). Also has an option to run at 10m.		
Grid Alignment	North-South grid orientation (unchanged from 002c)		
Model extent - Expanded in areas model is growing? - Model domain covers 2d code extent?	2d code changed from 002c. Has grown in areas where model is expanding and has been refined in dry areas of the model. **Boundary potentially needs to be extended to coast at Sandstone Park - discussed in 'Boundary Effects / Pooling' section.**	Model has been amended to reflect extended boundary	

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
Terrain - DEMs added / removed if now included in Lidar - 2019 Lidar - Bathymetry if applicable - Order being read in tgc - Modifiers/zsh	Topo order → - zpts = 1000 (changed from -0.5 mAHD - ok with as it will prevent large drops in elevation if there are gaps in lidar) - Included 2019 lidar - removed previous sections of 2009/2014 lidar - Maintained hydro grids in Ningi Creek and Elimbah Creek - **Gully lines - not being applied? Currently incorporated using Read GIS Z Line Gully which doesn't generate a check file so hard to tell - DEM Z suggests it's not working as well as Warning 2079. Please use the command Read GIS Z shape with GULLY or MIN specified in the shp file option attribute (not tgc).** - **Please spot check zpt values for gully lines to ensure points don't raise channel above what it should be.** - Zsh (Road Crest) - **Please spot check zshp's that enforce road crests (particularly legacy ones from 002c modelling). There may be instances where they are not tying in well with the new 2019 lidar (see below)**:	Gully lines have been amended. Road crests have been amended where appropriate Bruce Highway Diversion shapes were supplied by MBRC. Have been amended to better reflect topography – noted with MBRC to possibly follow up.	

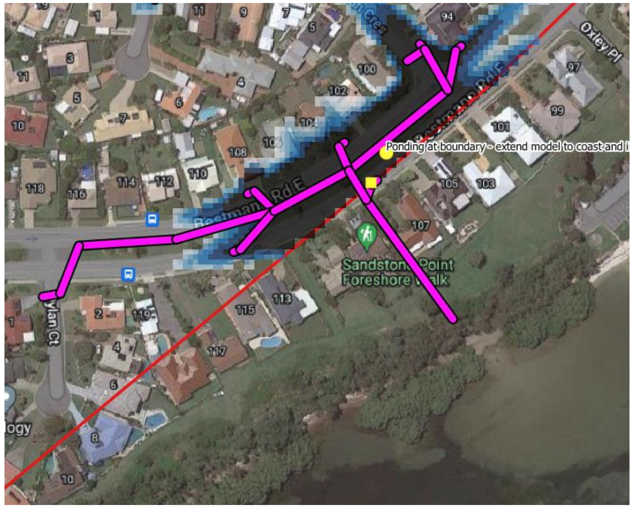
Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
	 - Zsh (channels) - appears ok - Bruce Highway Upgrade topography - highway design alignment, abutments for bridges, diversion channel - **see comment in Review_Comments.shp about diversion channel** - Bruce Highway water quality basins - DEMs are put in, then filled to get final ground levels - Fences and Guard Rails - appear to be applied correctly - see 'Other Structures' section - Bridges - see comments in 'Bridges' section - Topographic Amendments - appears ok - zsh at culverts to enforce road levels.		
Bridges - PORTION applied - Form losses, blockage, depths ok	PORTION applied (default in HPC) - L1_blockage applied to some structures (~5%) - I think these are legacy structures so are maintaining these values. - Please note - negative FLC's have been applied for some bridges (TMR bridges on Bruce Hwy). This approach applies the specified FLC at each cell face within the lfcsh polygon and is not cell size independent. I've noted you have scenarios setup for 5m and 10m cell size runs - **if it is the intention**	FLC have been amended accordingly Duplicate bridge names noted and altered.	

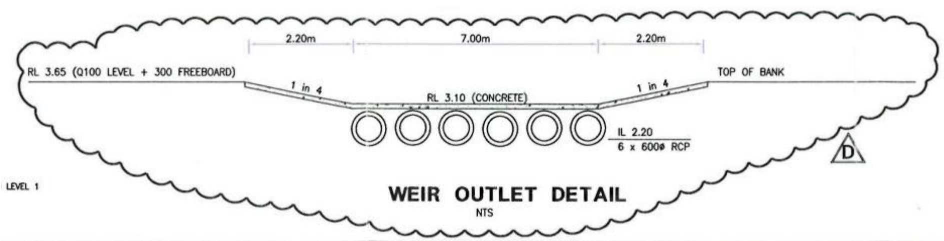
Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
	to run model at varying cell sizes, you will need to adjust these FLC's to be consistent between models. Please amend accordingly. - Please review FLC at 'BIR_01' - form losses are being applied incorrectly (haven't been divided by bridge width so total FLC is too large) - NOTE - at some legacy bridges, the old bridge polygons/points layer hasn't been used and new polygons are now used. Please clarify use of polygon over a polyline in these situations and not adopting old points for elevations. - At some bridges, FLC's are being applied to too many cell sides, so total FLC is too high. See below example where FLC should be applied to 2 cell sides but is applied to 3 due to lfcsh polygon extent. Please review lfcsh_uvpt_check and modify polygons to select intended number of cell sides. 		

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
	- **Have noted some comments on specific bridges in Review_Comments.shp** - **Noted - some duplicate bridge IDs - please ensure each bridge has a unique ID (is there something in the naming convention document for this?)**		
Other Structures - Adjustments as per “structures” section in brief - Fauna fences - Fences	Guard rails now included in model as lfcsh and are consistent with TMR guidance as per the brief. Total height of guard rail 0.39+0.36=0.75m. - L1_blockage = 5.5% - L1_FLC = 0.05 - L2_blockage = 100% - L2_FLC = 0.7 Fauna fences applied as line and point lfcsh - point elevations appear to have been sampled from lidar and a constant 1.8m has been added to specify fence height. Blockage (90%) and FLC (0.7) consistent with Barrier Assumptions tech note.		
Roughness - 2019 roughness dataset added - Waterbodies layer? - .mat values applied correctly? - Order being read in tgc correct?	2019 roughness raster added. Order being read appears correct. **Rail material applied as 19 instead of 18 - please amend** **Facilities applied as 18 instead of 19 - please amend** **Suggest renaming BitumenAndConcrete shp to Roads (consistent with .mat) as there is another layer called Concrete.** Csv for low grass grazing, low dense vegetation, medium dense vegetation and dense vegetation has not been updated as per suggested values in brief. **Please amend.**	Materials amended. Shapefile renamed to Roads to avoid confusion.	

<table>
<tr><th>Items checked</th><th>Corrections required</th><th>Description of corrective action taken</th><th>Corrective action taken by (signature)</th></tr>
<tr><td></td><td>
<table>
<tr><td>High Dense vegetation</td><td></td><td>Medium Dense Vegetation</td><td></td></tr>
<tr><td>y (m)</td><td>n</td><td>y (m)</td><td>n</td></tr>
<tr><td>0</td><td>0.05</td><td>0</td><td>0.05</td></tr>
<tr><td>1.5</td><td>0.05</td><td>1.5</td><td>0.05</td></tr>
<tr><td>3.5</td><td>0.1</td><td>3.5</td><td>0.075</td></tr>
<tr><td>99</td><td>0.1</td><td>99</td><td>0.075</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Low Dense Vegetation</td><td></td><td>Low Grass Grazing</td><td></td></tr>
<tr><td>y (m)</td><td>n</td><td>y (m)</td><td>n</td></tr>
<tr><td>0</td><td>0.03</td><td>0</td><td>0.25</td></tr>
<tr><td>1.5</td><td>0.03</td><td>0.025</td><td>0.06</td></tr>
<tr><td>3.5</td><td>0.055</td><td>0.05</td><td>0.045</td></tr>
<tr><td>99</td><td>0.055</td><td>0.1</td><td>0.035</td></tr>
<tr><td></td><td></td><td>2</td><td>0.025</td></tr>
<tr><td></td><td></td><td>99</td><td>0.025</td></tr>
</table>
Update names in Materials.csv accordingly:
“Low Grass Grazing.csv “ to “Open_Space_001.csv”
“Low Dense Vegetation.csv” to “Low_Density_Understory_001.csv”
“Medium Dense Vegetation.csv” to “Medium_Density_Understory_001.csv”
“High Dense Vegetation.csv” to “High_Density_Understory_001.csv”.</td><td></td><td></td></tr>
<tr><td>General bc_dbase check
- Inputs correct?</td><td>Bc_dbase seems ok. Inflows all locs. Constant tailwaters may need updating with latest MHWS advice (once MBRC provides this information).</td><td>Noted and supplied by MBRC. Adjusted accordingly</td><td></td></tr>
<tr><td>Inflow boundary
- SA polygons updated to latest
- Local inflow only for HEH
- Hydrography
- SA polygon locations reviewed</td><td>Note - last value in majority of inflow hydrographs in loc.ts1 have not been zeroed - therefore most SA inflows continue to generate some artificial flow. Something to be aware of when generating new hydrology in WBNM.
Additional SAs have been added in areas of refinements. Some refined areas causing new areas of inundation (probably to be expected).
Additional SA Pit inflow areas have been included in areas with pit and pipe network - this contributes to for new areas of inundation, sometimes on private property. In these areas, please check if pipe network is at</td><td>Noted. Legitimate flooding assessed in particular areas. Inclusion of trunk drainage undertaken to assist in informing real flood risk.</td><td></td></tr>
</table>

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
& adjusted mainly for steeper/smaller catchments	**capacity and if this flooding is legitimate. Would it be improved/eliminated if further drainage network was included? Is the proportion of flows being applied at the pits appropriate or is flooding overstated?** **Whilst we acknowledge flooding may occur in urban areas where pit/pipe capacity is exceeded, this may be better classified as overland flow, not river and creek flooding and shouldn't be shown as being flooded in a river and creek flood model. This may mean use of SA Pits is not always appropriate in areas of trunk drainage. A discussion point for next catchup.** There are some SA's on the coast at the downstream end of the model that are being applied directly on the HT outflow boundary - **please review SA's along the coast to see if this is appropriate. These flows exit the model at the HT boundary without flowing through the catchment.**		
Outflow Boundary - HQ, HT - Water surface slope check at boundary	Outflow boundaries are HT's applied at the downstream end of the model and are split into Donnybrook and Toorbul constant MHWS regions. As noted in 'Initial Conditions' section, MWHS values may need updating in line with most recent data.		
Boundary Effects / Pooling?	There are a few ponding locations along the coast that may need review (see example below). As per below screenshot, there is ponding at the boundary at Sandstone Park with SA being applied on the 2d_code. **Suggest extending code boundary to coast, including IWL and HT boundary and modelling the drainage network at that location draining into the bay. This ponding is potentially causing impacts to the north that shouldn't occur.**	Model amended to include this area	

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
	 **Please review boundaries to ensure there are no other areas with ponding that shouldn't occur.**		
Initial Conditions - IWL 1D and 2D - Farm dams assumed full	**Global initial water level of 0.76mAHD and 0.85mAHD applied to model in 1d and 2d for Donnybrook and Toorbul - this may need to be updated based on latest MHWS information**. **For small farm dams that impact on flow paths, please assume at full supply level and set individual IWL accordingly (or use a hot start with a frequent flood long duration event as previously discussed)**. IWL for lake at Sandheath Place should to be set individually - I believe that culvert 28_00581 is the outlet control for the lake (along the north-western edge of the lake as circled below). The existing culvert invert (2.7mAHD) from the previous 002c model appears to be too high. **As per the below culvert/weir screenshot, please model culvert invert at 2.2mAHD and set IWL of the lake to 2.2mAHD.**	IWLs adjusted. Farm dams included as IWL shapefile. Culvert inlet adjusted to 2.2 mAHD.	

Items checked	Corrections required	Description of corrective action taken	Corrective action taken by (signature)
	 		
Pipes Network - Inlets - Losses - Manhole Losses - Pit Blockage - Stability	Generally data in shp files appears ok. 1d_nwk_trunk_pits - Width_Dia attribute of 2 - is this big enough? There is 'node' in 1d_nwk_trunk_pits - please rename to 'Pit…' or similar as per other pits. It also has a length of 1 and form loss of 1.5 - is this necessary or should it be removed? Is this a carry-over from 002c? 1d_nwk_trunk_drains_L - for a couple of segments, Conn_No = 1 - what does this do? Should it be deleted?	Pits and pipes amended where required.	

<table>
<tr><th>Items checked</th><th>Corrections required</th><th>Description of corrective action taken</th><th>Corrective action taken by (signature)</th></tr>
<tr><td></td><td>One area of additional trunk drainage has been included at Sandstone park where model was ponding - see Extra_1dNetwork.shp</td><td></td><td></td></tr>
<tr><td>Culverts
- Connections
- Data applied correctly
- Stability: wobbly culverts, inflow vs outflow acceptable</td><td>Generally standard losses have been applied -
- R → 0.6, 0.9, 0.5, 1
- C → not used, 1, 0.5, 1

For the below R type culverts, please review losses to see if correct. Not consistent with other R type culvert losses in model:
<table><tr><td>35</td><td>SteveIrwin</td><td>R</td></tr><tr><td>36</td><td>18_05190</td><td>R</td></tr><tr><td>37</td><td>1140648</td><td>R</td></tr></table>- Lengths and dimensions appear reasonable
- Manning’s of 0.013 applied for all culverts - standard for concrete barrel.
- Inverts appear reasonable, no large differences in U/S and D/S identified. There are a handful of culverts that grade backwards - please review these locations although this may be legitimate.
- Mixture of SX point connections and SX line connections for larger culverts. Z flags applied to all SX. Please review warning messages for excessive lowering of topography.
- Majority of culverts appear stable - a few instabilities noted - see Review_Comments.shp for specific locations.
- Some missing culverts have been flagged - please include - see Extra_Culverts_PUM.shp. Where a few of these culverts are missing size data (width/dia/height), please assume a reasonable estimate.</td><td>Culverts amended where required.</td><td></td></tr>
<tr><td>Buildings</td><td>Materials file specifies Manning’s of 0.5 for buildings - good.</td><td></td><td></td></tr>
</table>

<table>
<tr><th>Items checked</th><th>Corrections required</th><th>Description of corrective action taken</th><th>Corrective action taken by (signature)</th></tr>
<tr><td colspan="4">Model Stability</td></tr>
<tr><td>Simulation finished?</td><td>Yes

SIMULATION SUMMARY

Input File: R:\Jobs\22020122_MBRC_RFD_Major_Model_Update_BCR_PUM\Analysis\PUM\TUFLOW\003a\Control\Runs\Design\PUM_R_003a_E_~e1~_~e2~_~s1~_05.tcf
Log File: \\FS07\results\22020122_PUM\TUFLOW\Log\5m\00100Y\0180m\\PUM_R_003a_E_00100Y_0180m_5m_05.tlf

Start Time (h): 0.
End Time (h): 12.
CPU Time: 2:32:06 [2.535 h]
Clock Time: 2:46:20 [2.772 h]

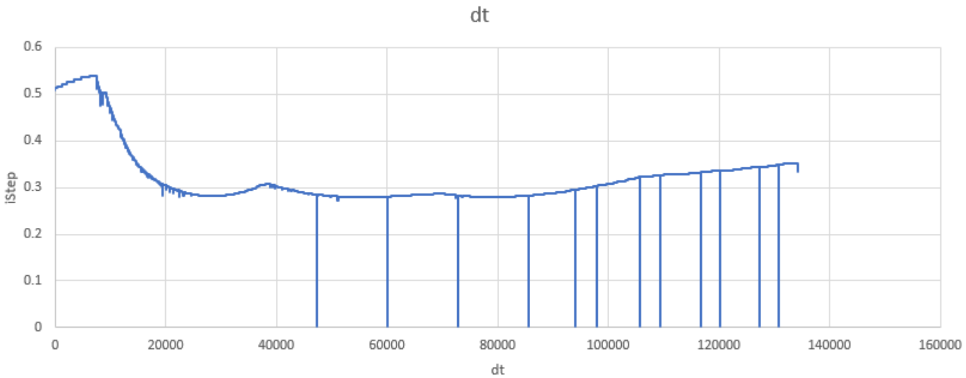
Simulation FINISHED</td><td></td><td></td></tr>
<tr><td>Review error / warnings</td><td>Please review messages shape file for warnings/errors.

Warning 2079 suggests gully/streamlines aren't be applied

Investigate Warning 2073 - warning appears where lfsch's are being applied. The lfcsh check file indicates that the flow constriction is being applied so not sure what the issue is

Warning 2118 - check for excessive lowering by SX Z flags</td><td>Streamlines applied properly</td><td></td></tr>
<tr><td>Minimum dt acceptable</td><td>Min dt is approx 0.3 which is acceptable - greater than 0.1 (1/10 of 1 second typical tuflow classic healthy timestep)</td><td></td><td></td></tr>
<tr><td>Control Number Check

- Nu (Courant Number) < 1
- Nc (Shallow Wave Celerity) < 1
- Nd (Diffusion Number) < 0.3</td><td><table><tr><th></th><th>Nu</th><th>Nc</th><th>Nd</th></tr><tr><td>Minimum</td><td>0.008957</td><td>0.519653</td><td>0.016663</td></tr></table>
Nu and Nc <1 and Nd <0.3</td><td></td><td></td></tr>
<tr><td>dt time series not erratic (plot dt in .hpc.dt.csv)</td><td>Dt seems to stay around 0.3 for most of simulation - occasionally drops down to low number and back up to 0.3 in the following step as seen in plot below - control numbers in the same timestep don't change with these temporary drops so probably ok</td><td></td><td></td></tr>
</table>

<table>
<tr><th>Items checked</th><th>Corrections required</th><th>Description of corrective action taken</th><th>Corrective action taken by (signature)</th></tr>
<tr><td></td><td>


Low dt in below screenshot doesn’t see any significant change in corresponding control numbers for that time step.</td><td></td><td></td></tr>
</table>

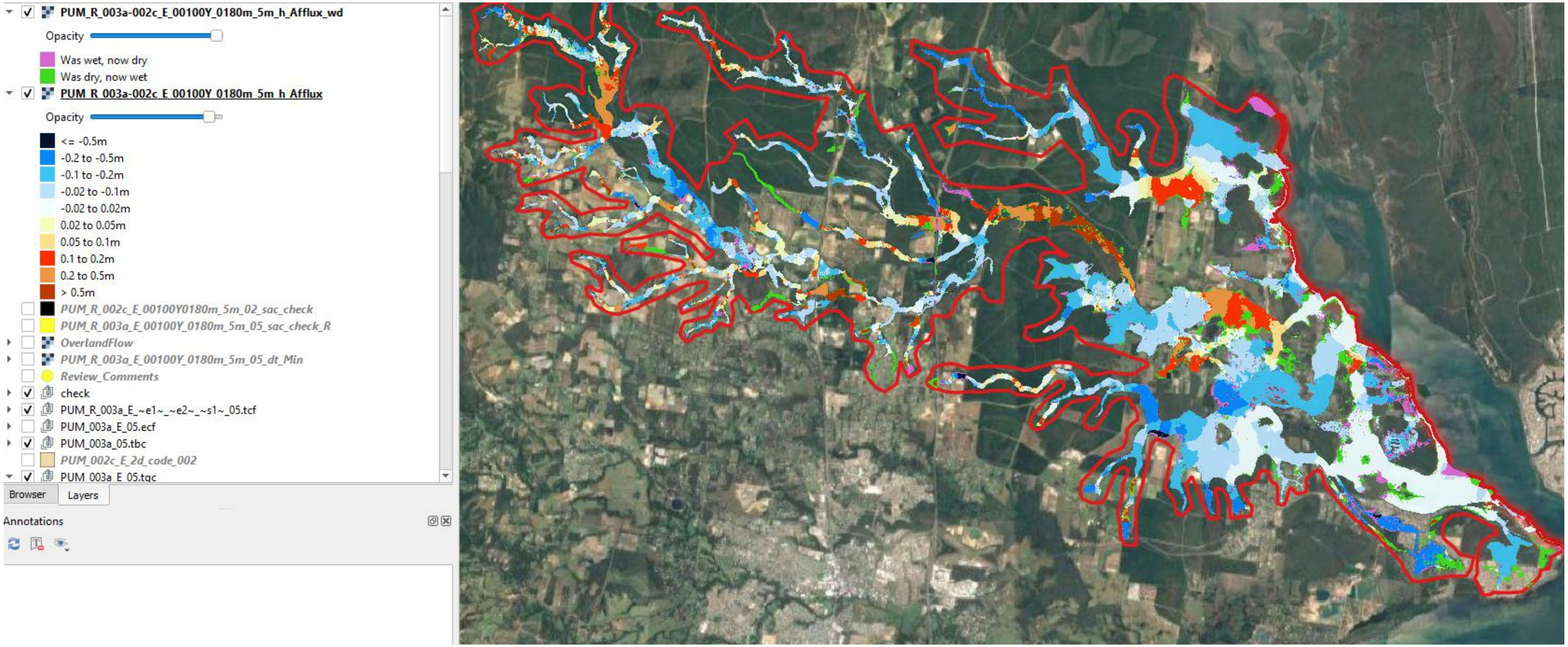
<table>
<tr><th>Items checked</th><th>Corrections required</th><th>Description of corrective action taken</th><th>Corrective action taken by (signature)</th></tr>
<tr><td></td><td>
<table>
<tr><th>iStep</th><th>tEnd</th><th>dtStar</th><th>dt</th><th>Nu</th><th>Nc</th><th>Nd</th><th>Eff</th></tr>
<tr><td>47297</td><td>16799.7</td><td>0.285867</td><td>0.285714</td><td>0.200302</td><td>0.559052</td><td>0.300003</td><td>99.5749</td></tr>
<tr><td>47298</td><td>16800</td><td>0.285864</td><td>0.285714</td><td>0.200302</td><td>0.559052</td><td>0.299988</td><td>99.5749</td></tr>
<tr><td>47299</td><td>16800</td><td>0.285876</td><td>0.001144</td><td>0.200302</td><td>0.559067</td><td>0.300003</td><td>99.5749</td></tr>
<tr><td>47300</td><td>16800.3</td><td>0.285873</td><td>0.285709</td><td>0.200302</td><td>0.559067</td><td>0.300003</td><td>99.5749</td></tr>
<tr><td>47301</td><td>16800.6</td><td>0.28587</td><td>0.285709</td><td>0.200302</td><td>0.559067</td><td>0.300003</td><td>99.5749</td></tr>
</table>
</td><td></td><td></td></tr>
<tr><td>Mass Balance: inflow = outflow + water on grid</td><td>Cumulative Mass Error [ME] (%) == 0 in .tsf</td><td></td><td></td></tr>
<tr><td>Repeat timesteps (NaN - not a number instability)</td><td>No</td><td></td><td></td></tr>
<tr><td>Repeat timesteps (HCN -high control number)</td><td>Yes - 2 - occur at very start of simulation (step 0) then no repeats for rest of simulation.</td><td></td><td></td></tr>
<tr><td>Spatial minimum dt check</td><td>Min dt flt indicates lowest dt is approx. 0.3</td><td></td><td></td></tr>
<tr><td>Outputs look sensible?</td><td>Comparing the 100yr 180min water levels between 002c and 003a (shown on next page):
- Generally, reductions are seen across large parts of the catchment
- Was dry now wet mostly in areas where inflow boundaries have extended, or SA pits is newly applied
- In some reaches through the mid to upper sections of the catchment, there are water level increases.

Differences are expected as there is:
- new topography
- significant change in the Manning's roughness
- new Wu viscosity
- new HPC solver
- New SA pit inflow locations or SA pit application

Please review newly flooded areas 'was dry now wet' in the model comparing 003a and 002c (particularly in urban areas) and assess whether the flooding is legitimate. Some areas have been flagged as part of this review, but this needs a comprehensive check.</td><td>Updated model includes significant adjustment and alteration of 2D_SA inflows as well as adjustment of model boundaries.</td><td></td></tr>
</table>

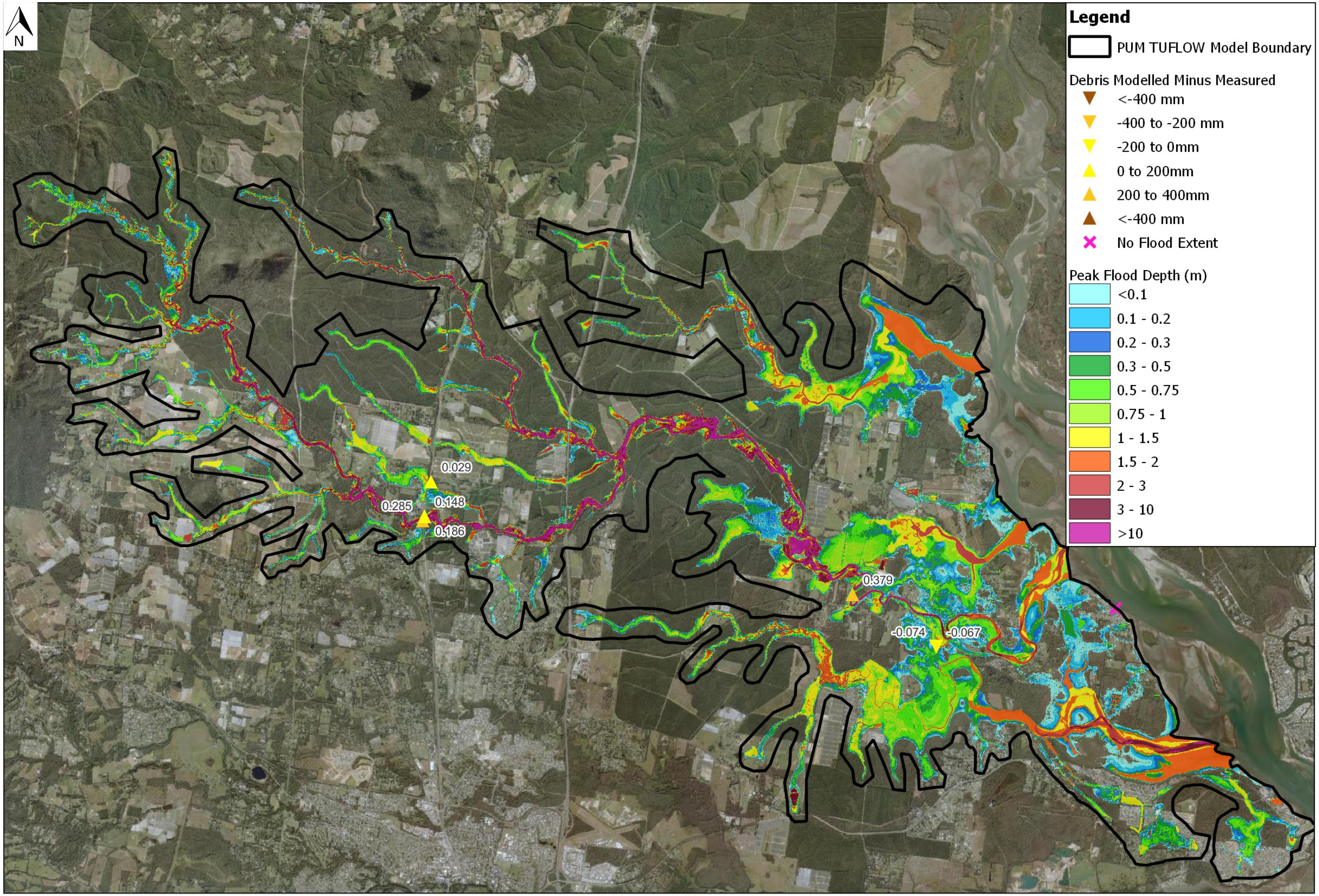
All design documentation checked and requested corrections satisfactorily incorporated ______________________ Date ________

(Signature of Verifier/Checker)



Difference: 100y ARI 180min - 003a - 002c water level

APPENDIX B
DEBRIS COMPARISON MAPS

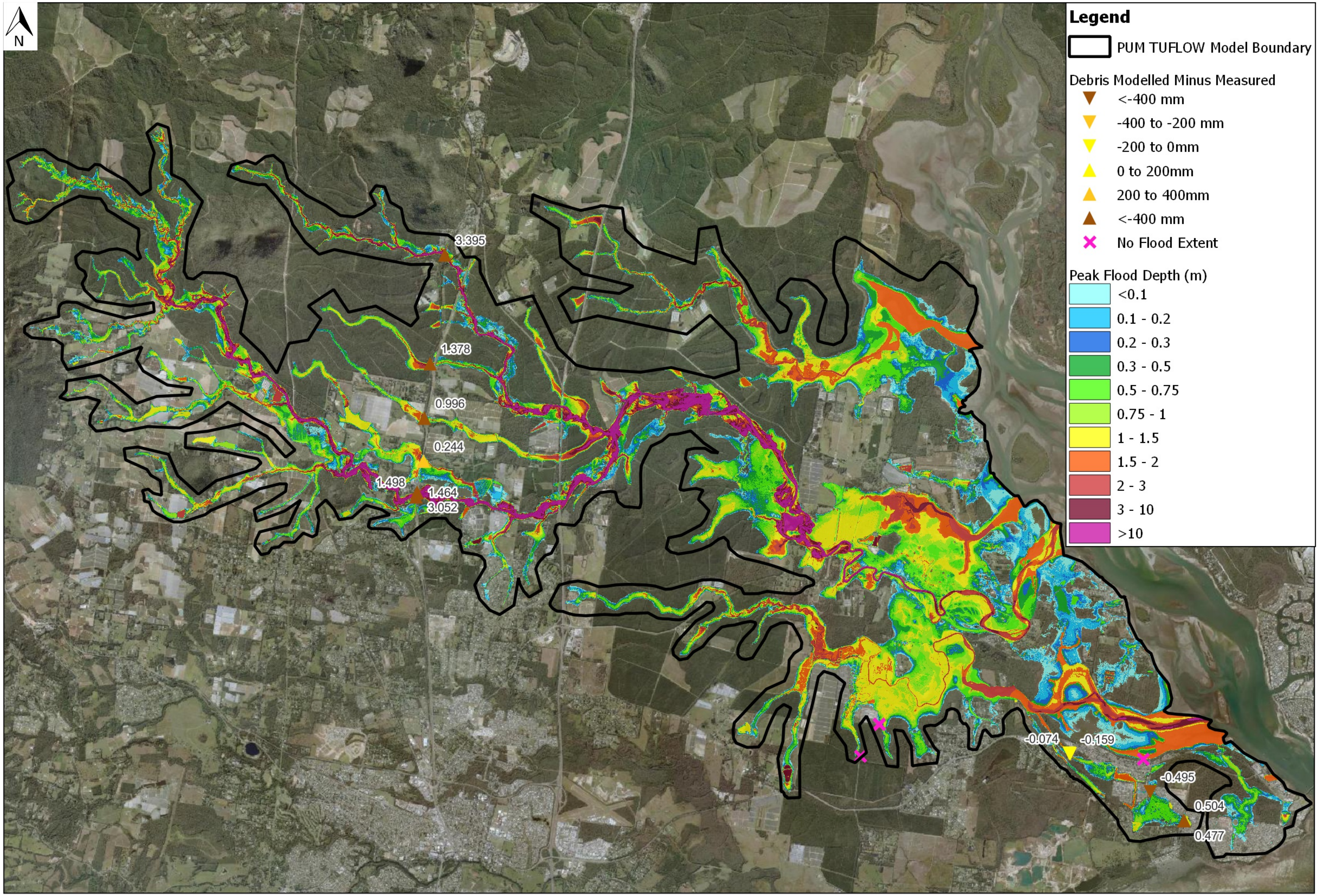


Projection: GDA94/MGA Zone 56
Water Technology Pty Ltd
1:75,000
0 1,000 2,000 3,000 4,000 m

22020122 MBRC RFD Major Update - PUM
February 2015 Calibration Event - TUFLOW Debris Comparison

WATER TECHNOLOGY

022-10-31T15:53:50.395



Projection: GDA94/MGA Zone 56
Water Technology Pty Ltd
1:75,000
0 1,000 2,000 3,000 4,000 m

22020122 MBRC RFD Major Update - PUM

May 2015 Calibration Event - TUFLOW Debris Comparison

WATER TECHNOLOGY

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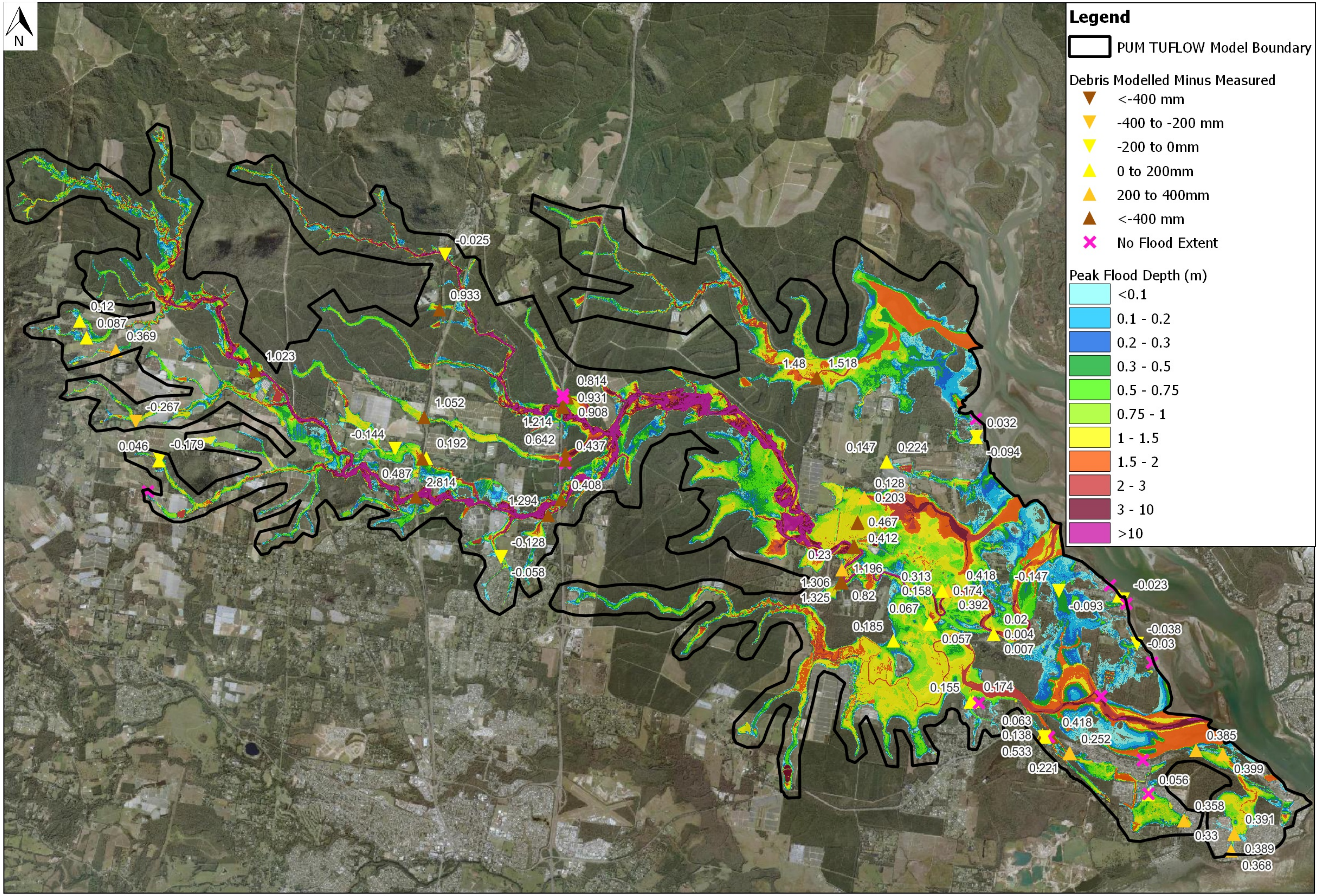

Projection: GDA94/MGA Zone 56
Water Technology Pty Ltd
1:75,000
0 1,000 2,000 3,000 4,000 m

22020122 MBRC RFD Major Update - PUM
May 2015 Calibration Event - TUFLOW Debris Comparison

WATER TECHNOLOGY

022-10-31T15:55:43.659

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