# Regional Flood Database:

## 2022 Major Model Update - Brisbane Coastal Creeks

Moreton Bay Regional Council

## Document Status

| Version | Doc type | Reviewed by | Approved by | Date issued |
|---|---|---|---|---|
| V01 | DRAFT | Carl Wallis | Alister Daly | 26/09/2023 |
| V01 | FINAL | Carl Wallis | Alister Daly | 18/10/2023 |
| | | | | |
| | | | | |

## Project Details

| | |
|---|---|
| **Project Name** | RFD Brisbane Coastal Creeks Major Model Update 2022 |
| **Client** | Moreton Bay Regional Council |
| **Client Project Manager** | Hester Van Zijl |
| **Water Technology Project Manager** | Alister Daly |
| **Water Technology Project Director** | Tony McAlister |
| **Authors** | Donnie Carroll |
| **Document Number** | 23020159_R01_V01_BCC_FINAL.docx |




Level 5, 43 Peel Street
South Brisbane QLD 4101
Telephone (07) 3105 1460
Fax (07) 3846 5144
ACN 093 377 283
ABN 60 093 377 283


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

# CONTENTS

## APPENDICES



## LIST OF FIGURES

# LIST OF TABLES

# 1 INTRODUCTION

Moreton Bay Regional Council (MBRC) is committed to continuously upgrading and enhancing its region wide hydrologic and hydraulic flood model library since its development in 2009, as part of the establishment of Council's Regional Flood Database (RFD). The RFD flood model library is capable of seamless interaction with a spatial database to efficiently deliver detailed information about flood behaviour across the MBRC area and for the local community. This report details the outcomes of Stages 4 and 5 of the MBRC RFD for the Brisbane Coastal Creek (BCC) Catchments. Figure 1-1 presents the location of the Brisbane Coastal Creeks 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.

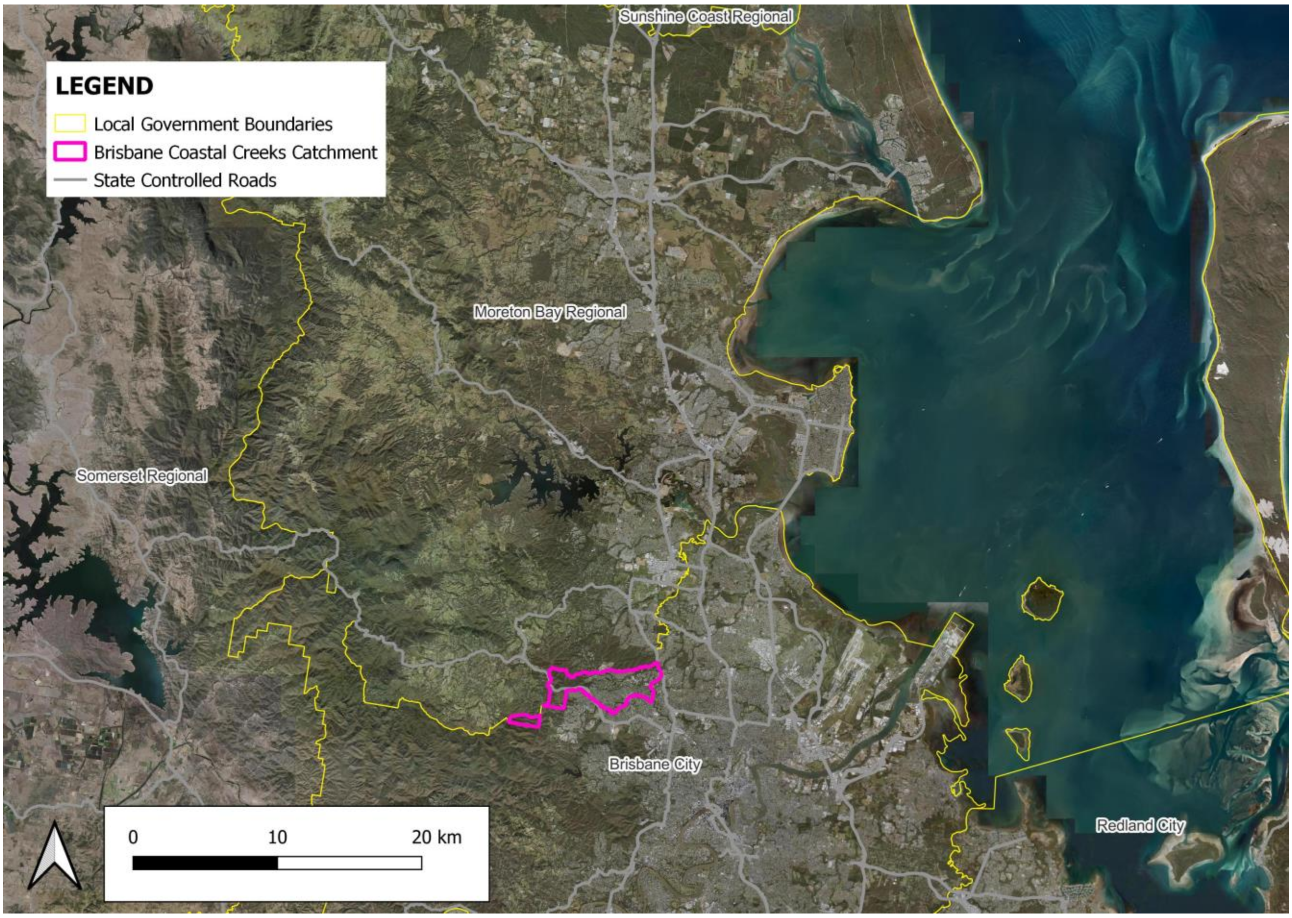



**Figure 1-1 Brisbane Coastal Creek Catchment within MBRC**

# 2 BACKGROUND

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

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

With these three Stages complete, this study represents the subsequent stages 4 and 5 for the Brisbane Coastal Creeks Catchment.

## 2.1 Catchment Description

The Brisbane Coastal Creeks model area is characterised by a combination of high-density urban areas, creek systems and densely vegetated National Park area in the upper parts of the catchment. Furthermore, the catchment is characterised by perennial creek systems, such as Cedar Creek, Kedron Brook Creek, and Cabbage Tree Creek. Each of these creeks flow Eastward into the Pacific Ocean.

# 3 2022 MAJOR FLOOD MODEL UPDATE DETAILS

## 3.1 ARR 2019

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

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

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

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

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

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

## 3.2 Rainfall Intensity-Frequency-Duration (IFD) Update

### 3.2.1 Intensities

Design flood estimates derived for the BCC 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 BCC catchment is presented in Table 3-1.

Table 3-1 ARR 2019 DataHub Parameters

| Parameter | Value |
|---|---|
| Longitude | 152.9308 |
| Latitude | -27.4062 |
| River Region | North East Coast |
| River Name | Brisbane River |
| ARF parameters | East Coast North |
| Storm Initial Losses (mm) | 14 |
| Storm Continuing Losses (mm/h) | 2.1 |
| 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. Appendix B presents the adopted impervious percentages for the respective scenarios.

### 3.3.3 Parameters

The Brisbane Coastal Creeks 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 initially informed by the calibration outcomes of neighbouring catchments and they were further validated by simulation of historical events and comparison to gauge readings and debris marks (see Sections 4 and 5).

### 3.3.4 Areal Reduction Factors

The pilot study recommended that the ARF be calculated at each POI and then run using 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 BCC model. Appendix D provides a table showing each POI and the subsequent area and ARF category applied for the design event modelling.

Table 3-2 ARF classification table

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

### 3.3.5 Preburst Application

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

Table 3-3 Preburst temporal pattern

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

### 3.3.6 Future Climate

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

### 3.3.7 Design Event Rainfall Losses

Without sufficient length of 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. 14 mm Initial Loss and 2.1 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 BCC catchment, a detailed 1D/2D TUFLOW model has been developed by updating the previous hydraulic model (RFD, 2015). 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.

WT has undertaken significant updates and improvements to the previous hydraulic model (RFD, 2015) 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 20 minutes for a 13 hour model simulation.
- Maintained fixed 5m grid with updated 2019 LiDAR.
- Refinement of roughness layers and adoption of depth-varying roughness to represent flooding more accurately in the catchment.
- Significant updates to the previously adopted 1D network files and inclusion of recently constructed structures.
- Updates of 2D structures including additions of guardrails and fauna fences.
- Update of inflow boundary types to be consistent with other RFD catchments.

### 3.4.1 Model Layout and Extents

The TUFLOW model code boundary covers most of the BCC catchment area. The code boundary extent has been modified into two separate sections to isolate modelling of Cabbage Tree Creek and upper Kedron Brook. Figure 3-1 shows the TUFLOW model code boundary adopted for the revised model and the LGA boundaries which intersect the model. Given there are some missing structures in the Brisbane City Council region and no validation to historical events has been undertaken in this region, the model should not be relied upon for accurate design flood levels in the Brisbane City Council areas. The previously adopted RFD model grid orientation of north-south, with no orientation angle has been maintained.

### 3.4.2 Model Topography

The model base topography is represented using 1.0 m resolution 2019 LiDAR data supplied by MBRC. Currently the model reads the latest survey over the previous 2015 TUFLOW model topography and subsequently supersedes the previous values where new data is available.

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.

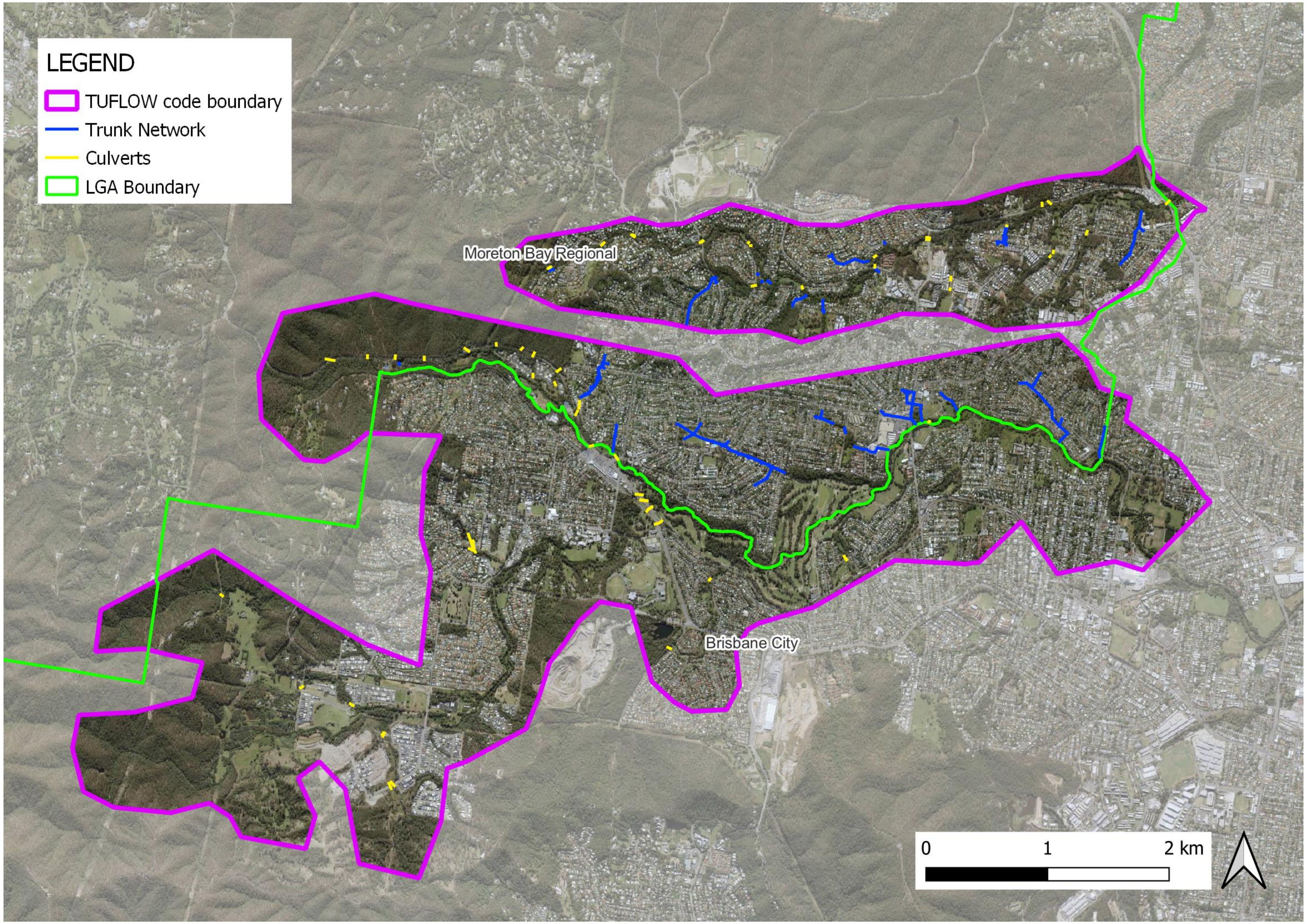



**Figure 3-1 Hydraulic model extent and structures**

### 3.4.3 Floodplain Structures

#### 3.4.3.1 Bridge Structures

All bridges were reviewed thoroughly and altered to comply with the modelling approaches discussed in the BMT technical memorandum. Specifically, the structures located in the BCC catchment, have complex geometries digitised with polygons. Therefore, method P2 was used to simulate these structures.

#### 3.4.3.2 Stormwater Pipes and Culverts

Significant discussion on the modelling of 1D network pits was undertaken with MBRC. For the Brisbane Coastal Creeks, the default pit (with no consideration of upstream pits) is modelled as a Q type pit linked with a single clearly-labelled “standard” pit curve (supplied by Council) and a multiplier of 2. This approach assumes that pit inlet capacity does not hinder the stormwater network capacity.

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

#### 3.4.3.3 Other Structures

On review of the provided model there were several cases of missing structures in the upper catchment of Kedron Brook. Design drawings were sourced from Brisbane City Council and structures have been subsequently added.

Similarly, there were several missing structures along Samford Road which is owned by the Queensland Government and therefore structures were not available within the Council GIS database. A site visit was undertaken by WT and structure sizes were estimated based on field measurements.

There were several guardrails and fauna fences added to the model as per the provided GIS files and these were modelled as per the guidelines provided in the tender documents.

### 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 3-2 shows the adopted depth varying roughness values. These values were determined through the calibration process of several other catchments in the MBRC region and further validated to comparison of stream gauge recordings and debris marks for three historical flood events in this catchment. Figure 3-3 illustrates the spatial variation in roughness applied in the hydraulic model.

Table 3-4 TUFLOW materials roughness values

| Material ID | Manning's n | Description |
|---|---|---|
| 1 | Low_Grass_Grazing_002.csv | Open Space (grasses) |
| 2 | Low_Dense_Vegetation_002.csv | Low Density Understory - Vegetation |
| 3 | Medium_Dense_Vegetation_002.csv | Medium Density Understory - Vegetation |
| 4 | High_Dense_Class1_Vegetation_002.csv | High Density Understory - Vegetation |
| 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 |
| 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 vegetation Class 1 | | |
| y (m) | n | | y (m) | n | |
| 0 | 0.05 | | 0 | 0.075 | |
| 1.5 | 0.05 | | 1.5 | 0.075 | |
| 3.5 | 0.075 | | 3.5 | 0.1 | |
| 99 | 0.075 | | 99 | 0.1 | |

Figure 3-2 Depth varying Manning's values

### 3.4.5 Inflow Boundaries

Model inflow 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 3-4. The SA polygons are distributed to 1D pit nodes where the trunk drainage is the main flow path through the catchment. For catchments where a clear creek or channel is the main conveyance a standard SA polygon is applied in which flow is initially distributed to the lowest elevation cell and then distributed proportioned by depth thereafter. There are no total inflows applied in the hydraulic model. Therefore, the routing is undertaken within the hydraulic model. The routing will be replicated in the WBNM hydrological model through a joint calibration process discussed in Section 5.

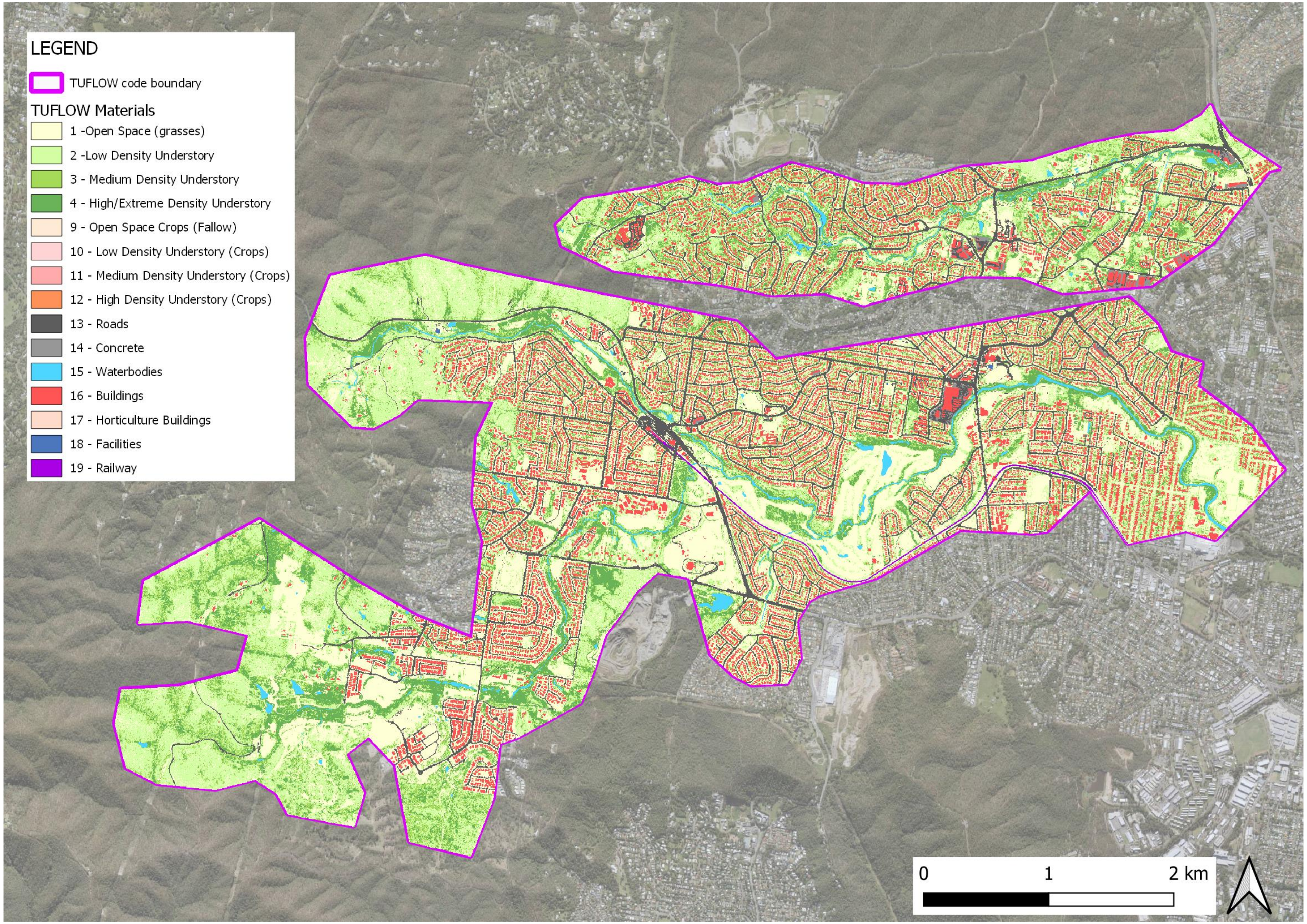



**Figure 3-3 Hydraulic model roughness layout**

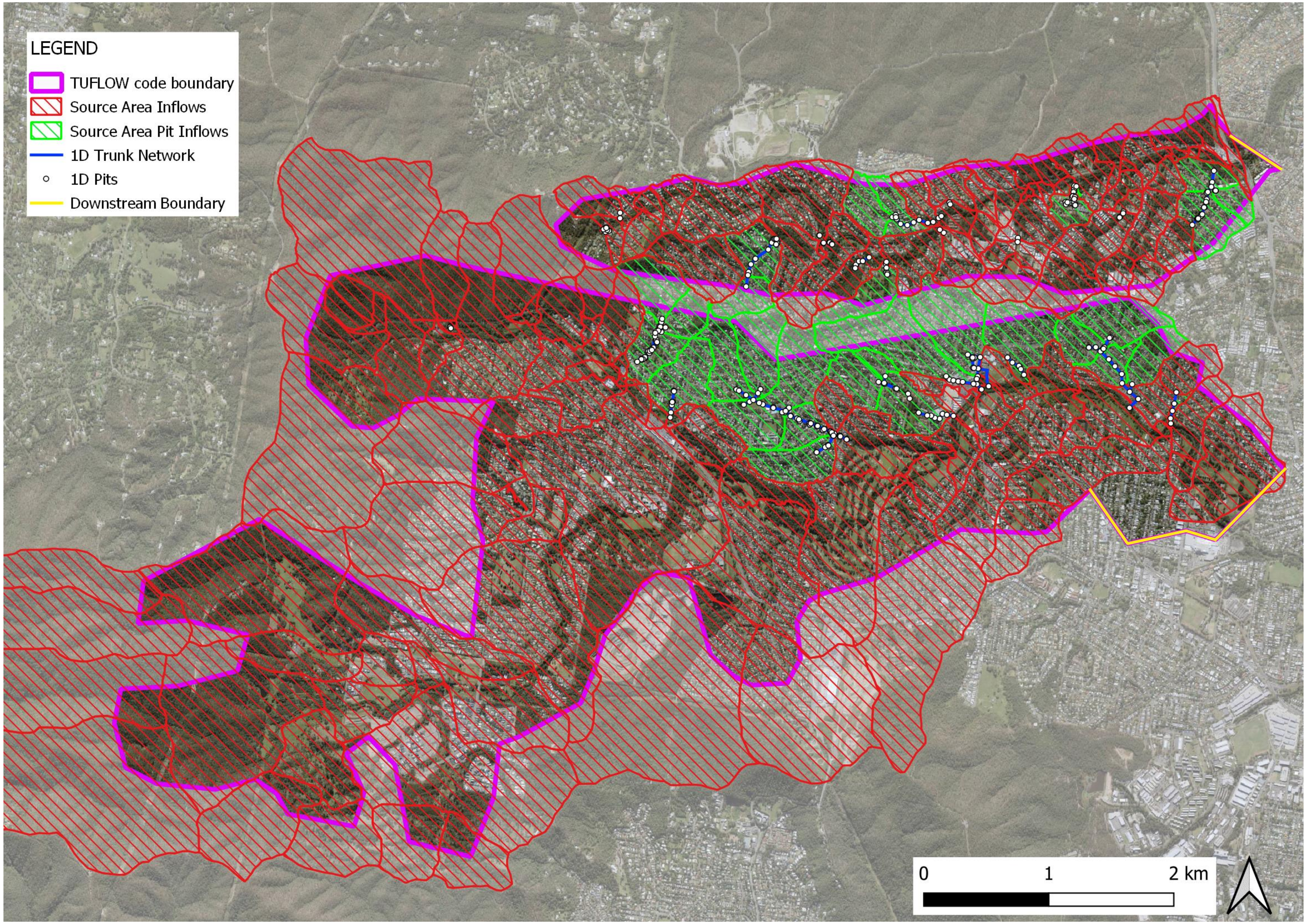



Figure 3-4 Hydraulic model trunk network and inflow boundaries

# 4 MODEL METHODOLOGY AND SIMULATIONS

## 4.1 Calibration to Historical Events

There are two available stream gauges located within the BCC Catchment. Debris data is also available for the February 2022 flood event. Table 4-1 outlines the flood events considered for the model validation.

**Table 4-1 Calibration event summary**

| Event | WBNM Start time | WBNM End Time |
|---|---|---|
| October 2010 | 10/10/2010 08:00 PM | 13/10/2010 08:00 PM |
| May 2015 | 30/04/2015 00:00 AM | 03/05/2015 11:55 AM |
| February 2022 | 23/02/2022 06:00 AM | 01/03/2022 00:00 AM |

### 4.1.1 Rainfall Data Available

MBRC supplied rainfall data at all rain gauge stations surrounding the BCC catchment. Table 4-2 summarises the available data for the respective events. Rainfall data was extracted for individual events by MBRC and was provided in CSV format. Figure 4-2 shows the location of the rainfall stations. Appendix A provides a detailed description of the rainfall data for the respective calibration events and how the rainfall was applied to the WBNM hydrological model.

**Table 4-2 Rainfall Gauges used for calibration**

| Gauge Name | ID | Event Availability |
|---|---|---|
| Everton Hill Alert | 540543 | All |
| Mitchelton Alert | 540635 | All |
| Samford Village Alert | 540652 | Not used October 2010 |
| Enoggera Dam Alert | 540653 | All |
| Three Ways Alert | 540110 | Not used October 2010 |

### 4.1.2 Stream Gauge Data Available

There are two (2) stream gauges located within the BCC study area, the details of which are outlined in Table 4-3. Figure 4-2 shows the location of the stream gauges.

**Table 4-3 Stream Gauges Used for calibration**

| Gauge Name | ID | Event Availability |
|---|---|---|
| Everton Hill Alert | 540543 | All |
| Mitchelton Alert | 540635 | All |

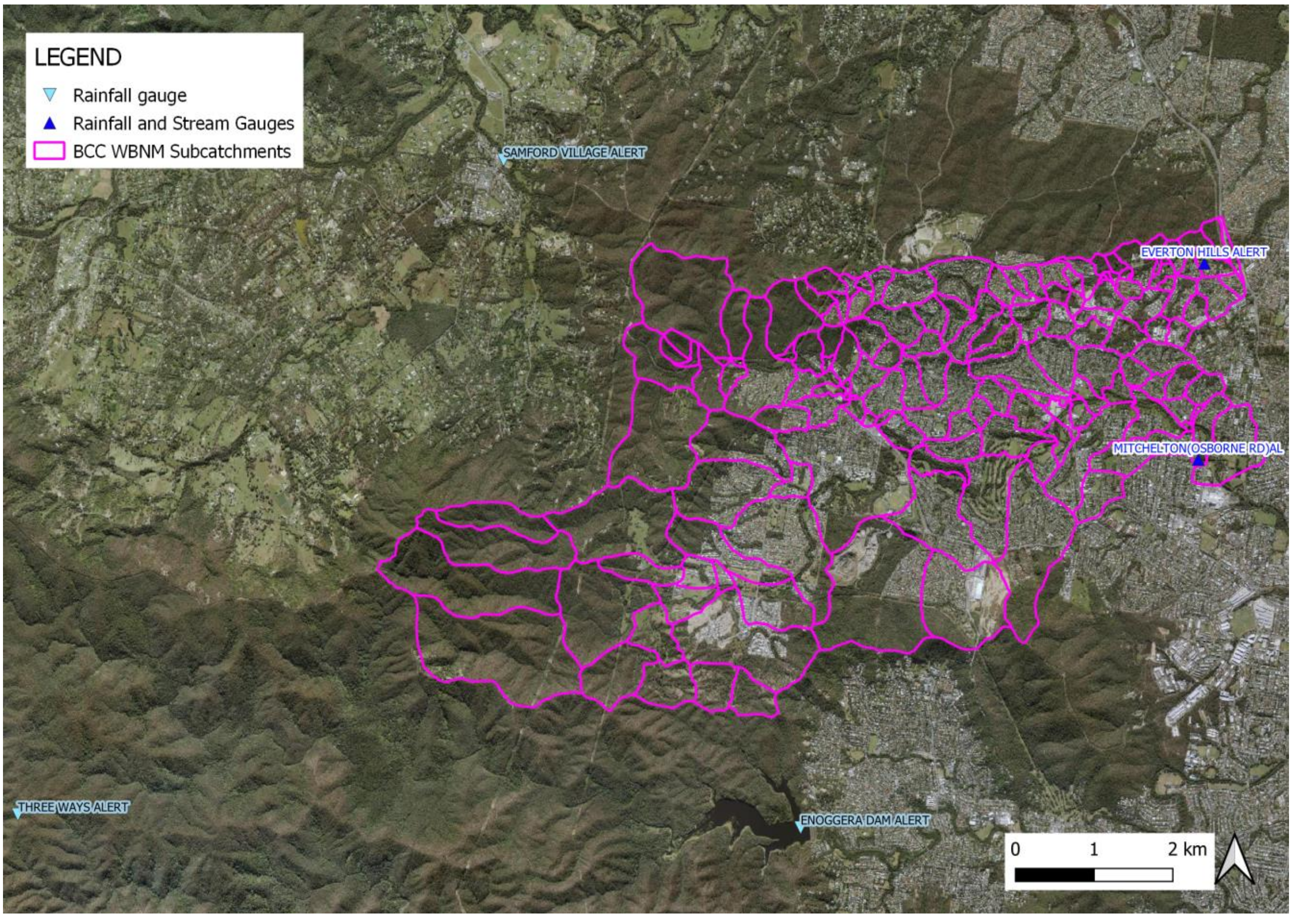



Figure 4-1 Rain and stream gauge locations

### 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 February 2022 validation event. It is noted that some debris marks were captured outside of the modelled flood extent and are most likely attributed to small overland flow paths rather than the intent of the model which is flooding from creeks and major overland flow paths.

Table 4-3 Debris mark availability summary

| Event | # of Debris Marks | # of Debris Marks in TUFLOW model extent |
|---|---|---|
| February 2022 | 11 | 11 |

### 4.1.4 Losses and Catchment Parameters

Table 4-4 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 stream gauge data.

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

| Event | Catchment Lag Parameter | Initial Loss (mm) | Continuing Loss (mm/hr) |
|---|---|---|---|
| October 2010 | 1.6 | 20 | 2.5 |
| May 2015 | 1.6 | 60 | 2.5 |
| February 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 BCC catchment. There are 17 POIs in total across the catchment. The following comments are noted outlining the decision-making process applied in selecting these locations:

- There are 17 POIs in total across the catchment.
- POIs have focused on the following locations (in this order of priority):
  - Key areas of known flooding hotspots as advised by MBRC.
  - Proximity to key flood evacuation roads.
  - Inflow locations from the Brisbane City Council catchment area.
  - Obtaining a spread of ARFs throughout the catchment – this also involved selecting “typical” BCC catchments. It was noted there are several small Moreton Bay draining catchments which have similar catchment features (landuse, area etc). Therefore, only one (1) of these catchments was selected noting that the critical duration and ARF will be applicable to similar catchments.

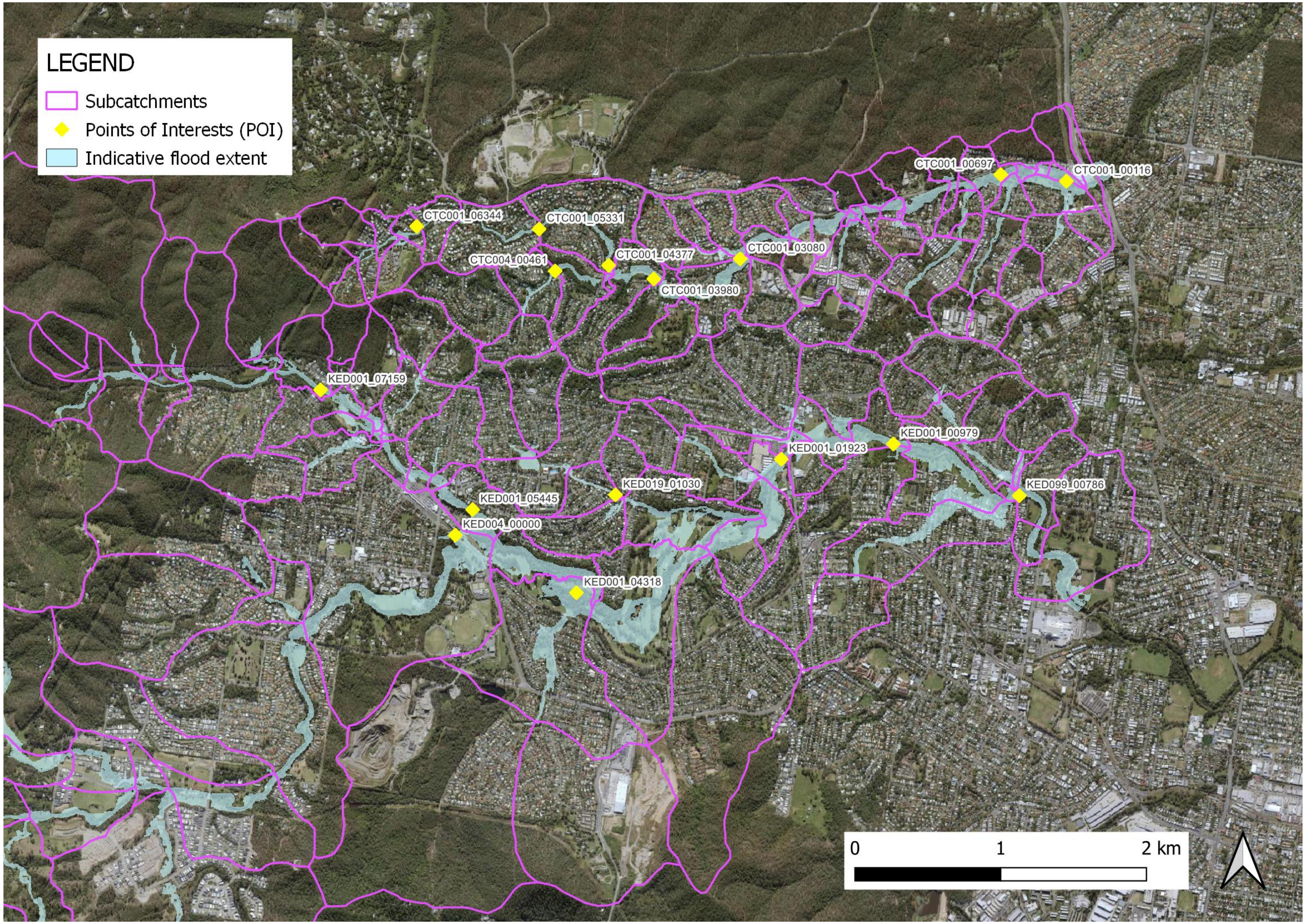



Figure 4-2 BCC Point of Interest locations

### 4.2.2 Methodology

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

- Simulated 3 different design flood events – 10%, 1% and 0.05% Annual Exceedance Probability (AEP). For each event both the 60-minute and 180-minute storms were simulated. The ARR1987 temporal patterns and IFDs were utilised. The durations were selected based on the dominant critical durations determined in the previous 2015 RFD BCC 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.

## 4.3 TUFLOW Hydraulic Model

### 4.3.1 Adopted Design Tailwater Conditions

A normal slope boundary has been applied at the outlets of both Kedron Brook and Cabbage Tree Creek.

### 4.3.2 Design Event Structure Blockage

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

**Table 4-5 Blockage matrix**

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

### 4.3.3 Model Simulations

#### 4.3.3.1 Existing Climate Simulations

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

#### 4.3.3.2 Future Climate Simulations

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

# 5 MODEL RESULTS AND OUTCOMES

## 5.1 TUFLOW Hydraulic Model Calibration Validation

### 5.1.1 October 2010

Figure 5-1 and Figure 5-2 show the comparison of water level hydrographs at the two (2) stream gauges located within the BCC study area with the TUFLOW model plot outputs for the October 2010 flood event. As shown in Figure 5-1, the modelled water levels provide a reasonable comparison to the recorded water level at the Everton Hills Alert gauge with a peak modelled level of 44.3 mAHD compared to a recorded height of 44.1 mAHD. The timing and shape of the modelled water level hydrograph confirms that an excellent representation of the October 2010 event has been replicated at this location. The comparison water level at the Mitchelton Alert, as shown in Figure 5-2 shows the model is overestimating flood levels at this location by approximately 850 mm although the timing and shape of the hydrographs are encouraging. There is limited spatial rainfall coverage in the upper parts of the Kedron Brook catchment which may be contributing to this difference in the results.

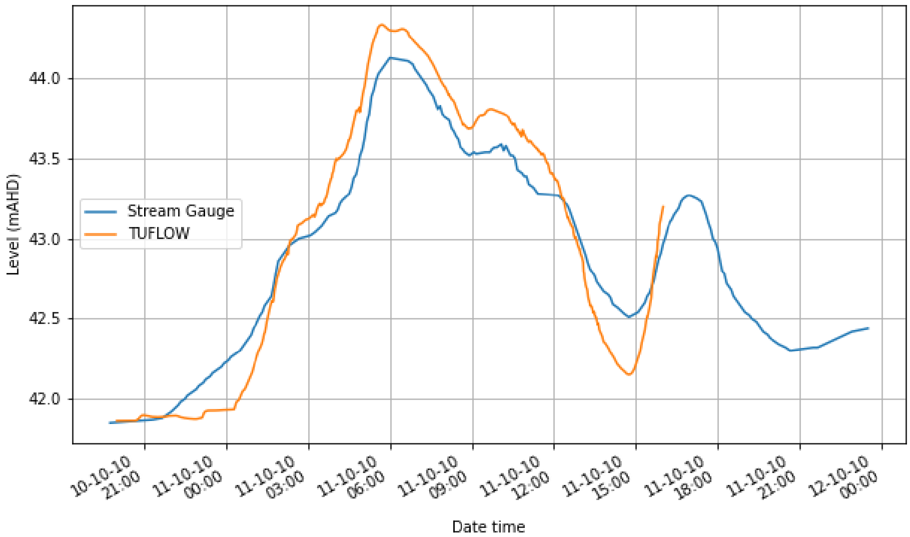



**Figure 5-1 Everton Hills Alert October 2010**

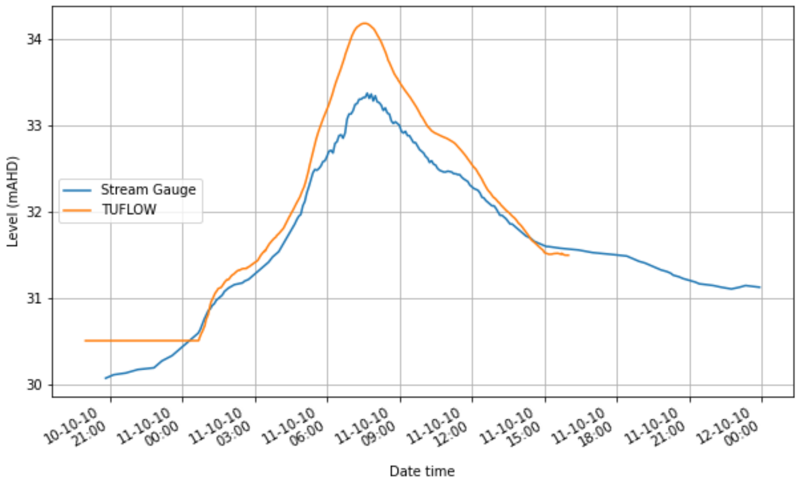



**Figure 5-2 Mitchelton Alert October 2010**

### 5.1.2 May 2015

Figure 5-3 and Figure 5-4 show the comparison of water level hydrographs at the two (2) stream gauges located within the BCC study area with the TUFLOW model plot outputs for the May 2015 flood event. As shown in Figure 5-3, the modelled water levels provide a good comparison to the recorded water level at the Everton Hills Alert gauge with a peak modelled level of 44.5 mAHD for both. The timing and shape of the modelled water level hydrograph confirms that an excellent representation of the May 2015 event has been replicated at this location. The comparison water level at the Mitchelton Alert, as shown in Figure 5-4 shows the model is overestimating flood levels at this location by approximately 900 mm although the timing and shape of the hydrographs are encouraging. Significant sensitivity testing was undertaken at this gauge location where consideration of blockage was modelled. However, this did not show any significant improvement in results to warrant changes in parameters given the agreeable calibration at the neighbouring Cabbage Tree Creek. Furthermore, there is limited spatial rainfall coverage in the upper parts of the Kedron Brook catchment which may be contributing to this difference in the results.

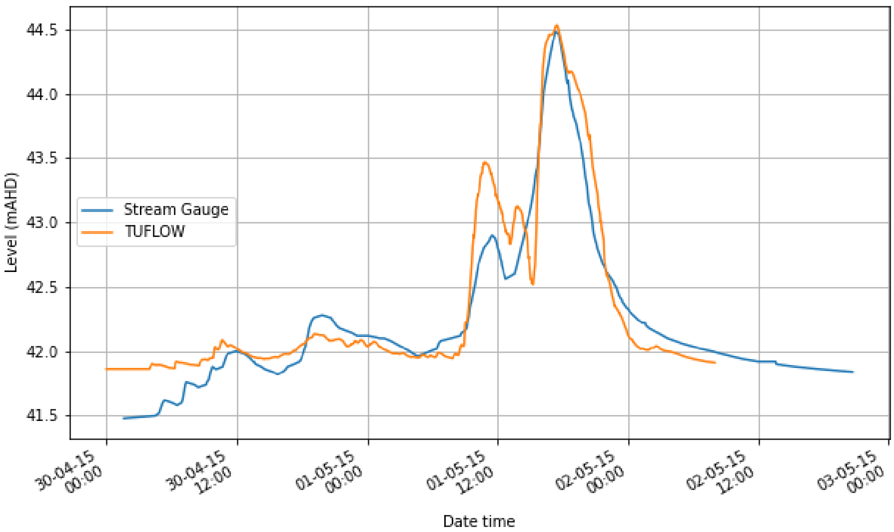



**Figure 5-3 Everton Hills Alert May 2015**

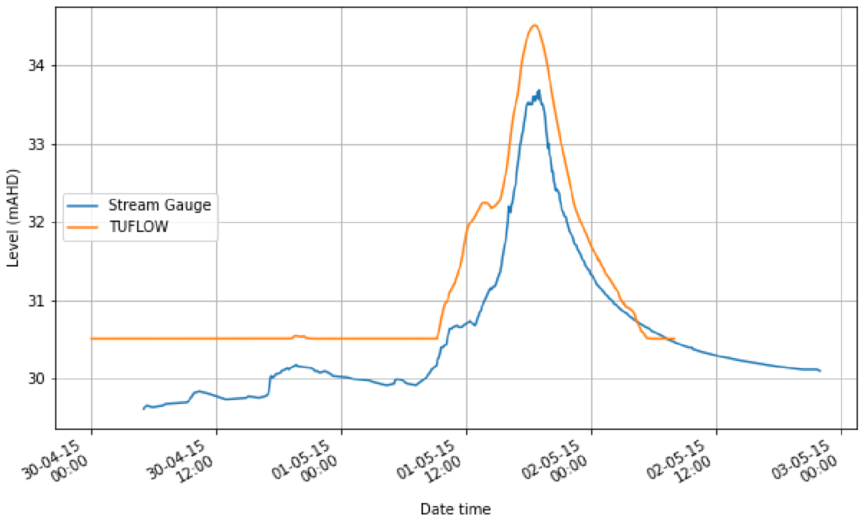



**Figure 5-4 Mitchelton Alert May 2015**

### 5.1.3 February 2022

Figure 5-5 and Figure 5-6 show the comparison of water level hydrographs at the two (2) stream gauges located within the BCC study area with the TUFLOW model plot outputs for the February 2022 flood event. As shown in Figure 5-5, the modelled water levels provide a good comparison with respect to peak, timing and shape to the recorded water level at the Everton HIlls Alert gauge. Similarly the modelled water level compared favourably at the Mitchelton Alert with a good match of peak, shape and timing, as shown in Figure 5-6.

Figure 5-8 presents spatial map of the hydraulic model validation results when comparing the TUFLOW model results to the surveyed flood depths for the February 2022 flood event. Figure 5-7 provides the histogram distribution of the differences. Overall, the hydraulic model has performed reasonably well in matching the observed flood marks. Approximately 27% of the markers were within 100 mm and approximately 55% of the modelled depths were within 300 mm of the measured levels. Considering the uncertainty of the observed debris mark measurements the results are considered reasonable.

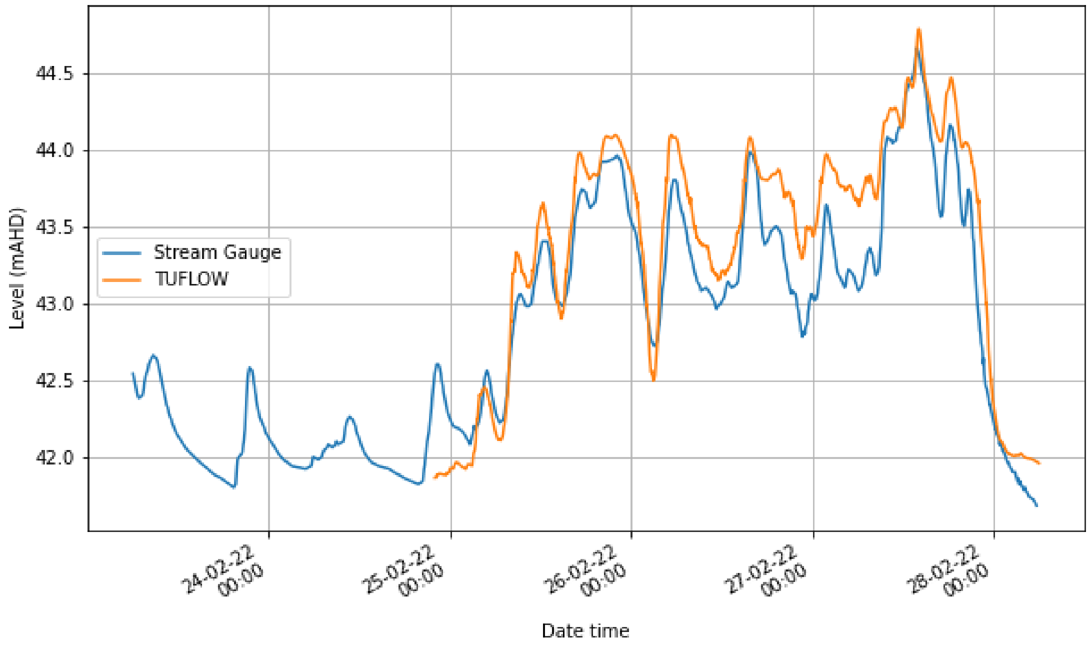



**Figure 5-5 Everton Hills Alert February 2022**

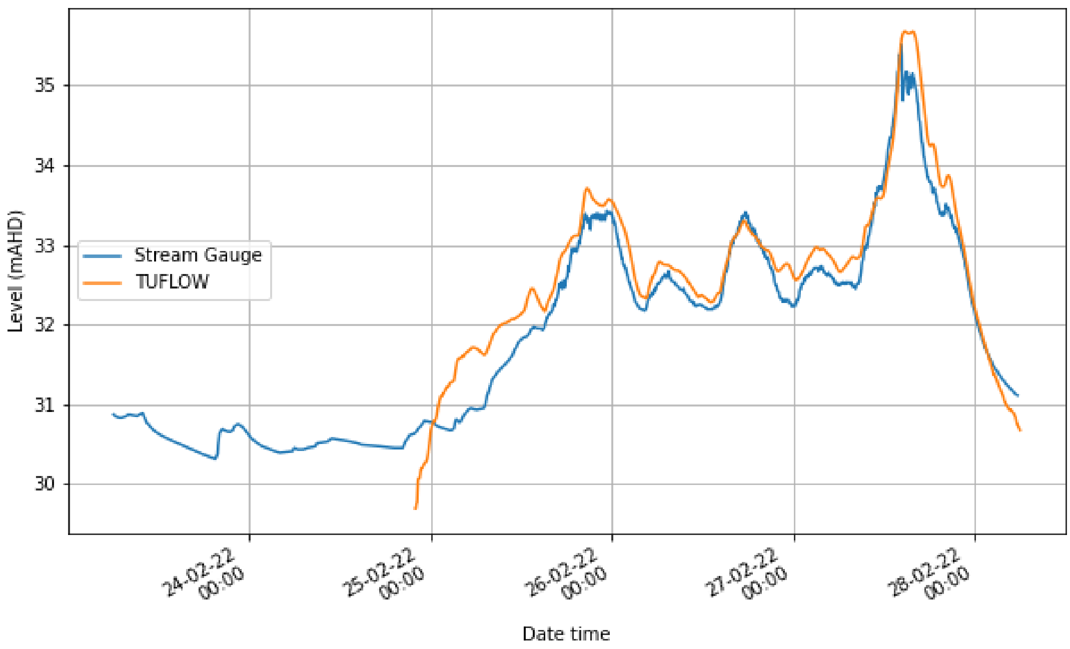



**Figure 5-6 Mitchelton Alert February 2022**

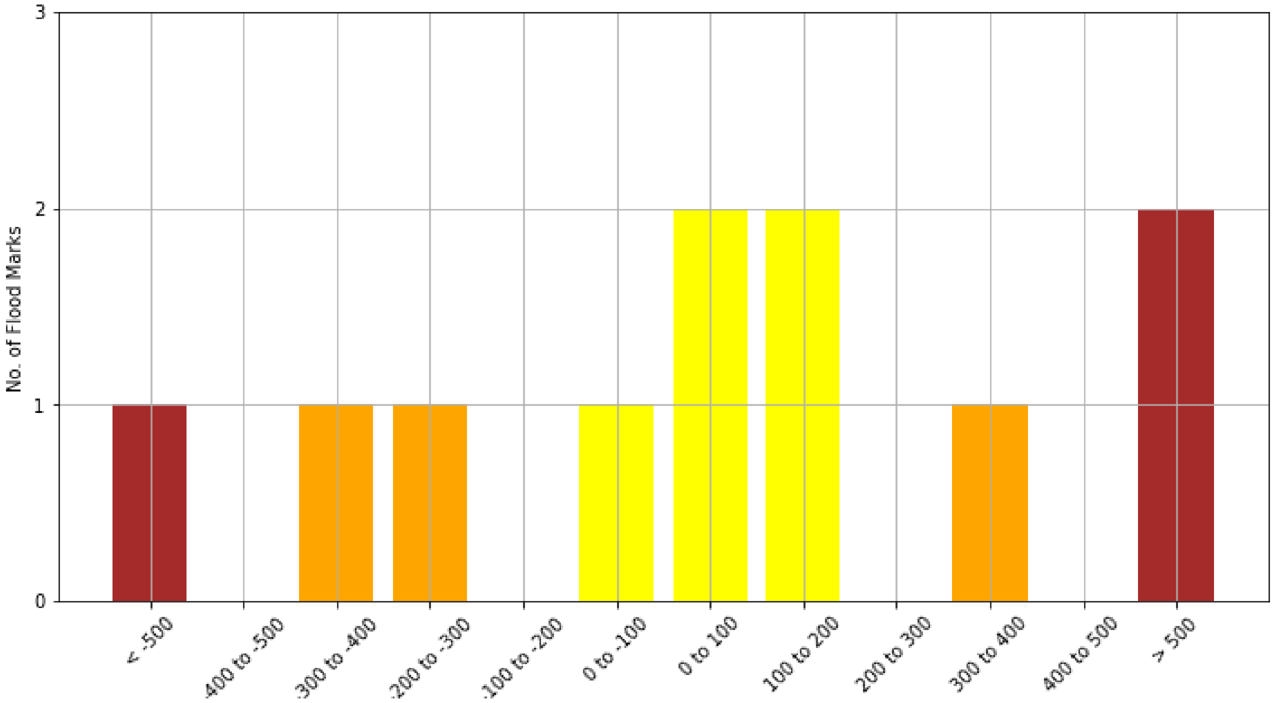



**Figure 5-7 February 2022 Difference in flood levels – modelled minus measured**

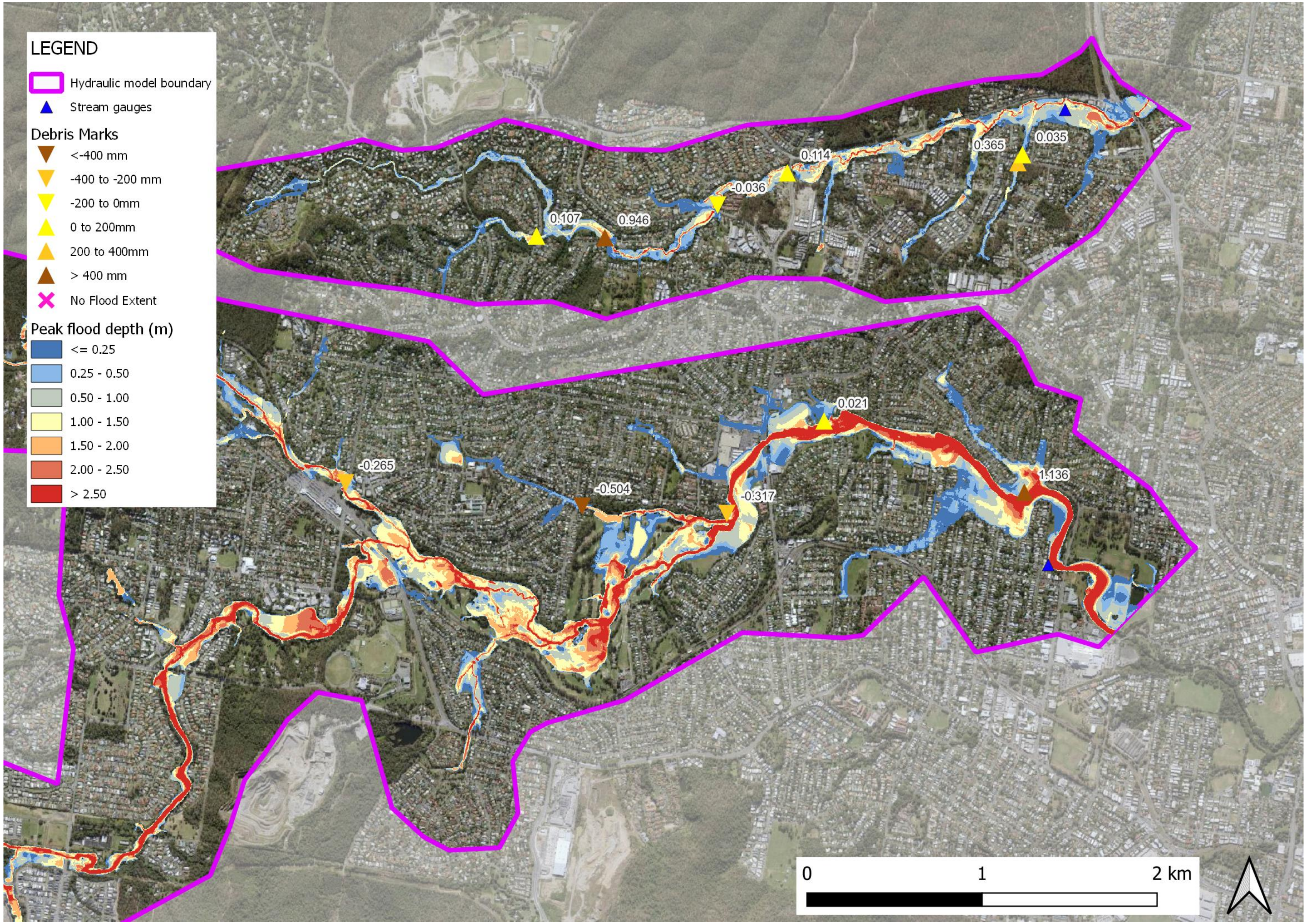



**Figure 5-8 BCC February 2022 – extent and debris locations**

## 5.2 WBNM Hydraulic Equivalent Hydrologic Model performance

Appendix C provides a tabular description of the results and plots/statistic tables for each simulated event/duration at each POI. The HEH modelling was undertaken to add confidence that the BCC WBNM model is representing the catchments hydraulic response (where possible) through alteration of stream routing parameters and the addition of artificial storage curves. Four (4) of the 17 POI locations required artificial storage curves added into the WBNM model. This process of HEH is ultimately undertaken to assist with the design storm selection based on advice outlined in the Stage 1 Pilot Study.

Only six (6) 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. 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, justification has been provided with a description of the results which generally meet the prescribed criteria although not for all 6 events.

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 hydraulic characteristics of the catchment. Based on this and the encouraging results achieved given the challenges of the catchment, the BCC HEH model is suitable to inform design event storm selection.

### 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.

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

From this analysis there was approximately 5 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 3 storms to the actual critical peak flow (from all storms) across all POIs. All possible combinations of critical storms were tested, and the optimal subset of storms was selected for each AEP based on the mean and minimisation of outlier flow differences. In general, this over or underestimation was aimed to be under +-10%.

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

Table 5-1 Critical events selected

| Event | Simulated events |
|---|---|
| 20% | 60min TP01 ARFa, 180min TP03 ARFd, 270min TP07 ARFd |
| 10% | 60min TP07 ARFa, 120min TP10 ARFb, 180min TP02 ARFd |
| 5% | 45min TP07 ARFa, 90min TP06 ARFb, 180min TP02 ARFd |
| 2% | 45min TP05 ARFa, 90min TP05 ARFb, 270min TP07 ARFd |
| 1% | 45minTP05 ARFa, 90min TP05 ARFb, 270min TP01 ARFd |
| 1 in 1000 | 30min TP10 ARFa, 60min TP01 ARFb, 270min TP07 ARFd |
| 1 in 2000 | 45min TP05 ARFa, 60min TP03 ARFb, 270min TP07 ARFd |

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 |
| KED099_00786 | 1% | 0% | 0% |
| KED001_01923 | 0% | 1% | 2% |
| KED001_07159 | 0% | -8% | 0% |
| CTC001_06344 | -2% | -4% | -8% |
| CTC001_04377 | -3% | 4% | -8% |
| CTC004_00461 | -1% | 1% | -5% |
| CTC001_03980 | 2% | 9% | -2% |
| CTC001_03080 | 0% | 3% | 2% |
| CTC001_01137 | 0% | 0% | 3% |
| CTC001_00697 | 0% | 0% | 0% |
| CTC001_00116 | 7% | 10% | 8% |
| KED001_05445 | 9% | 9% | 7% |
| KED001_04318 | 3% | 9% | 5% |
| KED001_00979 | 0% | 0% | 0% |
| CTC001_05331 | -3% | 0% | 0% |
| KED004_00000 | 3% | 8% | 6% |
| KED019_01030 | 0% | -1% | -5% |

## 5.3 Design Flood Behaviour

#### 5.3.1.1 Peak Flow Comparison

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

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

| POI | WBNM Duration (min) | WBNM Adopted TP | WBNM Peak Flow | TUFLOW Duration (min) | TUFLOW Adopted TP | TUFLOW Peak Flow |
|---|---|---|---|---|---|---|
| KED019_01030 | 60 | TP03 | 18.80 | 45 | TP05 | 17.71 |
| CTC004_00461 | 25 | TP08 | 15.13 | 45 | TP05 | 15.63 |
| CTC001_06344 | 25 | TP08 | 16.08 | 45 | TP05 | 15.55 |
| CTC001_05331 | 45 | TP05 | 24.67 | 45 | TP05 | 25.53 |
| CTC001_04377 | 45 | TP03 | 31.59 | 45 | TP05 | 34.29 |
| KED001_07159 | 90 | TP09 | 83.73 | 45 | TP05 | 83.47 |
| CTC001_03980 | 45 | TP06 | 51.19 | 45 | TP05 | 58.81 |
| CTC001_03080 | 60 | TP01 | 60.06 | 45 | TP05 | 71.50 |
| CTC001_01137 | 90 | TP05 | 86.16 | 90 | TP05 | 91.17 |
| CTC001_00697 | 90 | TP05 | 96.45 | 90 | TP05 | 103.42 |
| KED001_05445 | 90 | TP05 | 95.44 | 90 | TP05 | 103.93 |
| CTC001_00116 | 90 | TP09 | 93.69 | 90 | TP05 | 112.14 |
| KED004_00000 | 120 | TP01 | 173.04 | 90 | TP05 | 212.90 |
| KED001_04318 | 120 | TP03 | 251.23 | 90 | TP05 | 292.83 |
| KED001_01923 | 270 | TP07 | 319.64 | 90 | TP05 | 338.31 |
| KED001_00979 | 270 | TP07 | 324.69 | 90 | TP05 | 334.31 |
| KED099_00786 | 270 | TP01 | 337.61 | 90 | TP05 | 368.47 |

#### 5.3.1.2 Comparison to RFD 2014

Figure 5-9 presents the difference in peak flood level between the RFD 2022 (this study) and the previous RFD 2014 peak flood level across the catchment for the 1% AEP event (both unblocked scenarios). In general, there is a reduction in peak flood levels within the main creek channels of up to 500 mm in Kedron Brook and approximately 200 mm in Cabbage Tree Creek. Peak flood levels are generally within 500 mm of previous results. The changes are most likely attributed to the change in hydrologic guidelines i.e. ARR 2019 and revised design rainfall intensities, and also revised Manning's n delineation and values. This study has significantly increased the modelled flood extent with more flow paths modelled hydraulically along with more refined subcatchment inflow locations.

A similar comparison has been undertaken for the Design Flood Event (DFE) which for this major update is the enveloped future climate 1% AEP scenario. Figure 5-10 presents a comparison of flood levels of the 2022 RFD DFE to the RFD 2014 DFE which was based of the Median Duration Storm (MDS). Similarly, flood levels have generally decreased although there are increases particularly upstream of major structures where the blockage methodology has been revised.

A comparison of the blocked and unblocked scenarios showed that blockage increased flood levels up to 200 mm at key structures throughout the catchment. There are 2 major structures along Cabbage Treek Creek where flood levels have increased significantly by over 500 mm.

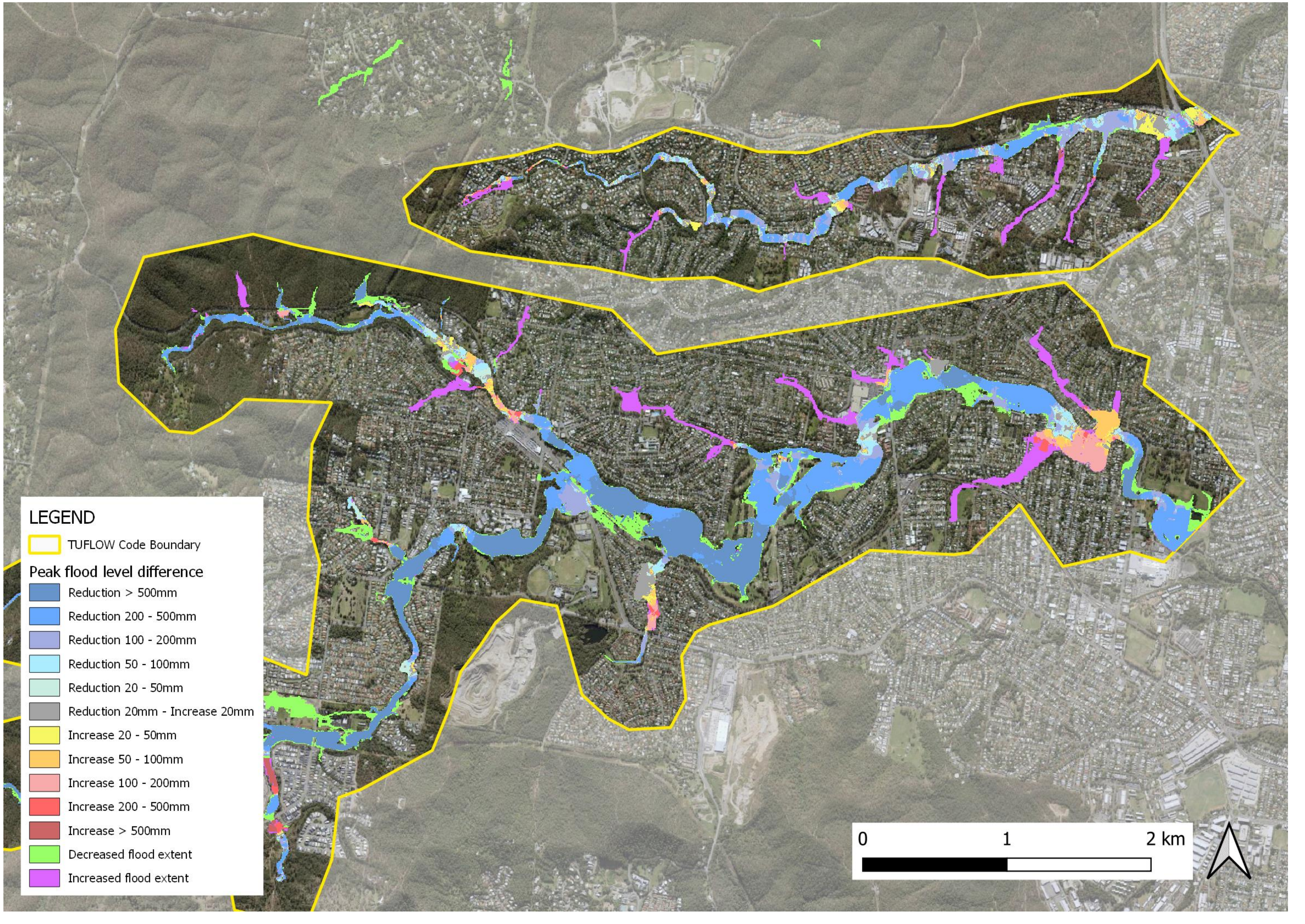



**Figure 5-9 RFD 2022 minus RFD 2014 1% AEP peak flood level (unblocked)**

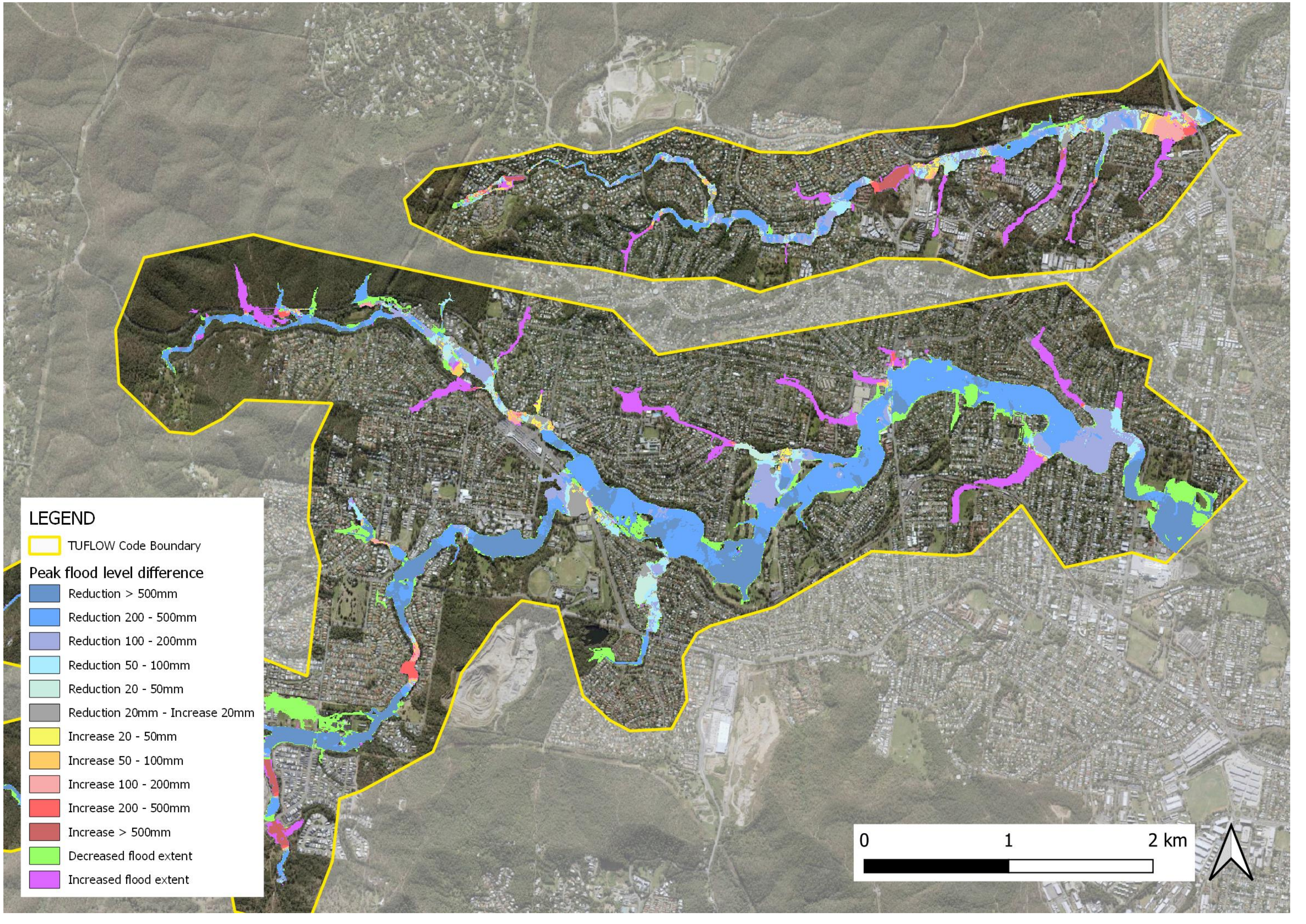



**Figure 5-10 RFD 2022 minus RFD 2014 1% AEP DFE peak flood level (future climate)**

## 5.4 Model Limitations and Quality

A plot showing the control numbers and minimum timestep (dt) during the 1% AEP 90-minute event (E02) is shown in Figure 5-11. 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 BCC 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 adopted model roughness was based on previous work undertaken by in the Stage 2 study and endorsed by MBRC. Spatially, the materials layers are highly refined and represent a substantial improvement from the previous RFD modelling.

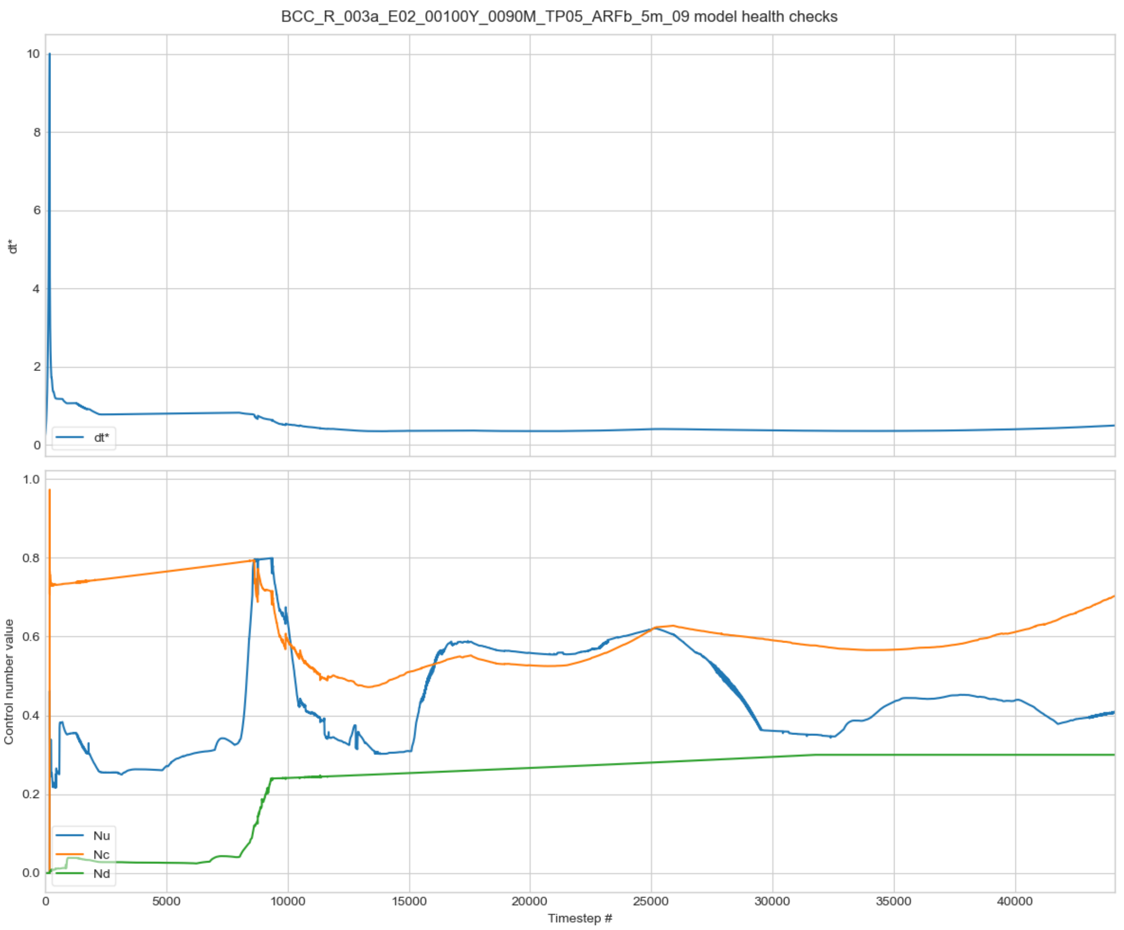



**Figure 5-11 TUFLOW model health check**

## 5.5 Model Specification and Run Times

BCC is one of the smaller catchments within the MBRC RFD study area, encompassing 24.76 $km^2$ and 2,956,176 grid cells (at 5m cell size). Table 5-4 provides a summary of the BCC TUFLOW model specification and run times. It is noted that runtimes will vary depending on CPU and GPU hardware used.

**Table 5-4 BCC model specification and run times**

| Event | Model run time (hours) (varies per duration) | Startup Memory (MB) | GPU memory required (MB) |
|---|---|---|---|
| 20% AEP (180min) | 0.25 | 1200 | 610 |
| 1% AEP (90min) | 0.25 | | |
| 1 in 2000 AEP (60min) | 0.25 | | |

# 6 CONCLUSION

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

The primary objective of the project was to deliver the TUFLOW model and its associated outputs in a digital format. Therefore, this report presents only a selected subset of the results obtained from the model. The focus was on providing the necessary information that can be readily integrated into the database and utilized for further analysis and management of flood risk in the BCC 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 BCC catchment, aiding in the assessment and management of flood risk. The information obtained from the model will support informed decision-making processes related to floodplain management, land-use planning, and infrastructure development in the area. It will also be used in all MBRC public flood mapping products such as the Flood Check Reports and Moreton Bay Flood Viewer.

Overall, the development and delivery of the models for the BCC 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 BCC catchment representing a significant improvement over previous iterations.

It is important to note that although the models have been validated to two (2) stream gauges and to historical debris marks there remains significant uncertainty in model parameters. The stream gauges are limited to the downstream locations of the tributaries with limited validation data in the upper parts of the catchment. It was noted there is a lack of rainfall spatial coverage in the upper Kedron Brook catchments which may have caused overestimation of the downstream Mitchelton gauge in 2 of the 3 validation events. Additional rainfall gauges within the BCC catchment would add significant value to future calibration/validation events and model iterations. This calibration to additional historical events (with improved rainfall coverage) 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. LIMB 2020 IFD - High Resolution, available at: https://data.arr-software.org/
4. Memorandum - IFD Sensitivity – Redcliffe - RFD 2022, Water Technology 2022
5. Memorandum - Final HEH Modelling Methodology, BMT, 2022
6. Moreton Bay Regional Council Regional Flood Database ARR 2019 Pilot Study Part 1 Methodology Report & Part 2 Pilot Study Report, ARUP, 2021
7. Regional Flood Database - Hydrologic and Hydraulic Modelling – BCC, Aurecon, 2012
8. Regional Flood Database - 2015 Model Maintenance Report – BCC, Water Technology, 2015
9. Regional Flood Database - Stage 2 - Hydrography Landuse and Hydrology, AECOM, 2020
10. Regional Flood Database – Stage 3 Analysis Summary, Moreton Bay Regional Council, 2021

# APPENDIX A
# CALIBRATION EVENT RAINFALL ASSESSMENT

# A-1 Rainfall Application

## A-1-1 October 2010

Hydrological data from the rainfall stations at Enoggera Dam, Everton Hills and Mitchelton (Osborne Rd) were utilised to generate the spatial distribution of rainfall in the October 2010 event. Figure A-1 and Figure A-2 present the cumulative and sub-daily rainfall plots for the Everton Hills and Mitchelton (Osborne Rd) Alert rainfall stations, respectively.

Rainfall was distributed using the standard WBNM method which assigns rainfall depths to each subcatchment based on a weighted average depth calculated using the nearest pluviograph station data. The weights are calculated based on the inverse square of the distance between the pluviography station and the sub-area centroid. Figure A-3 presents the spatial distribution of the total rainfalls across the modelled WBNM subcatchments. The event was very localised around the Everton Hills locality and rainfall total gradually reduced in a south-westerly direction.

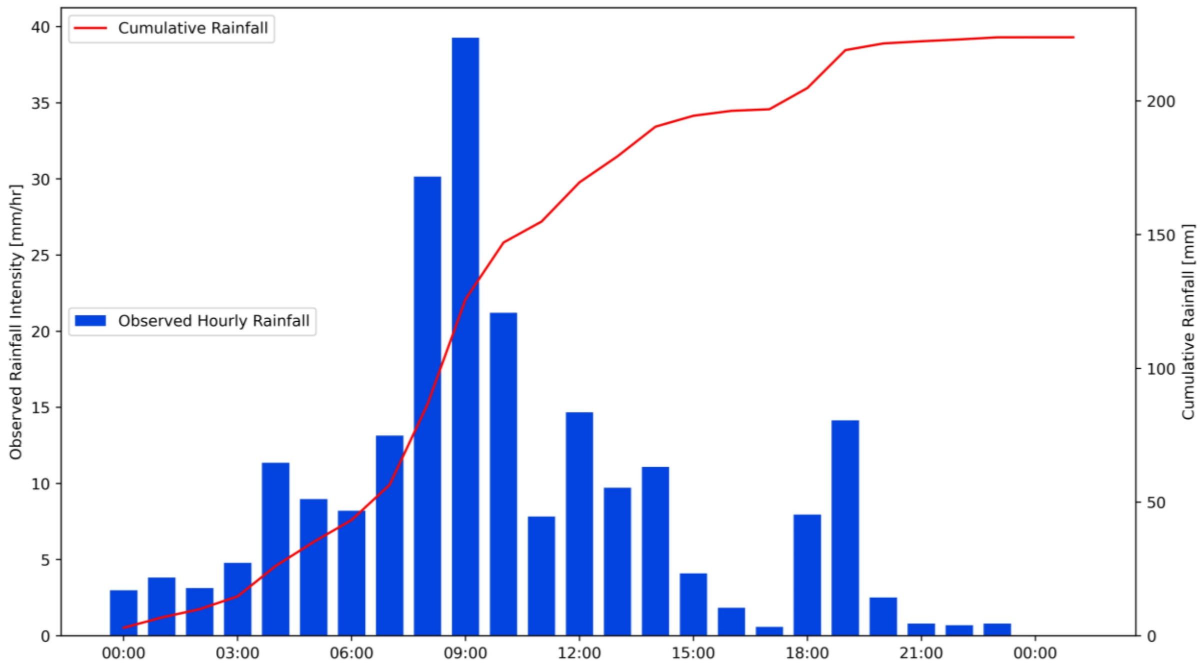



Figure A-1 Cumulative and sub-daily rainfall plot during the May 2015 event for Everton Hills Alert

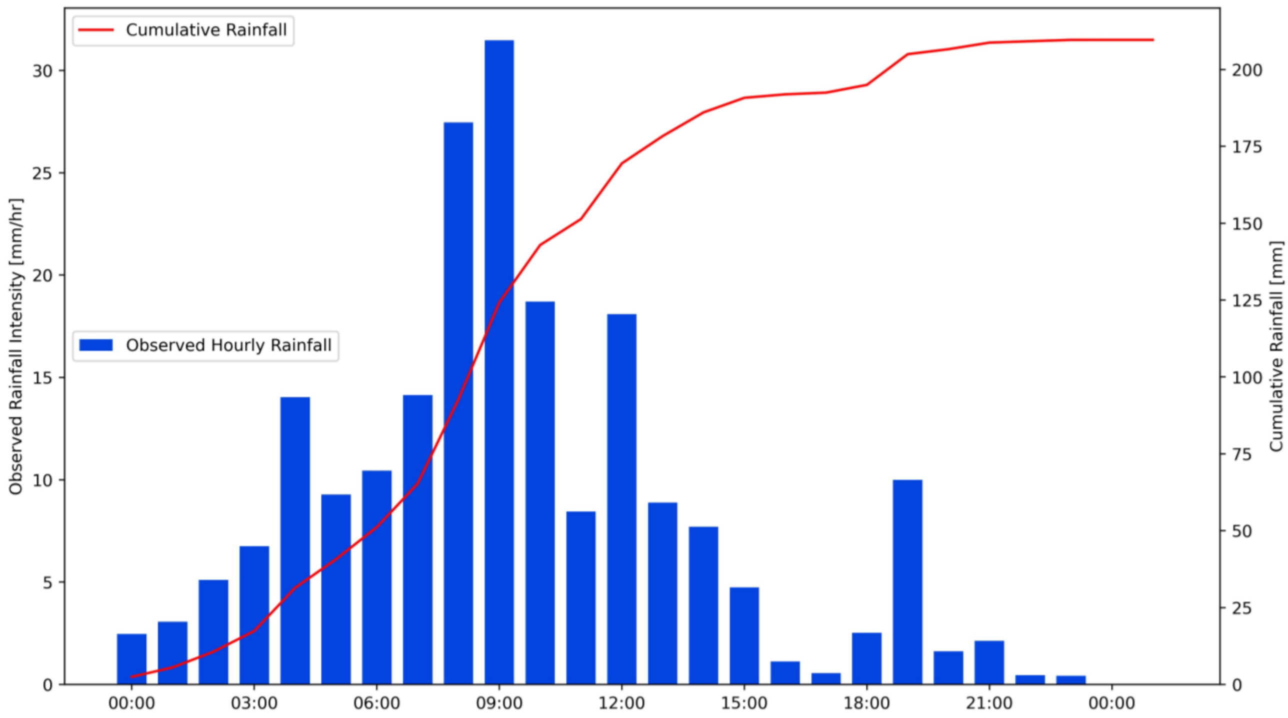



Figure A-2 Cumulative and sub-daily rainfall plot during the May 2015 event for Mitchelton Alert

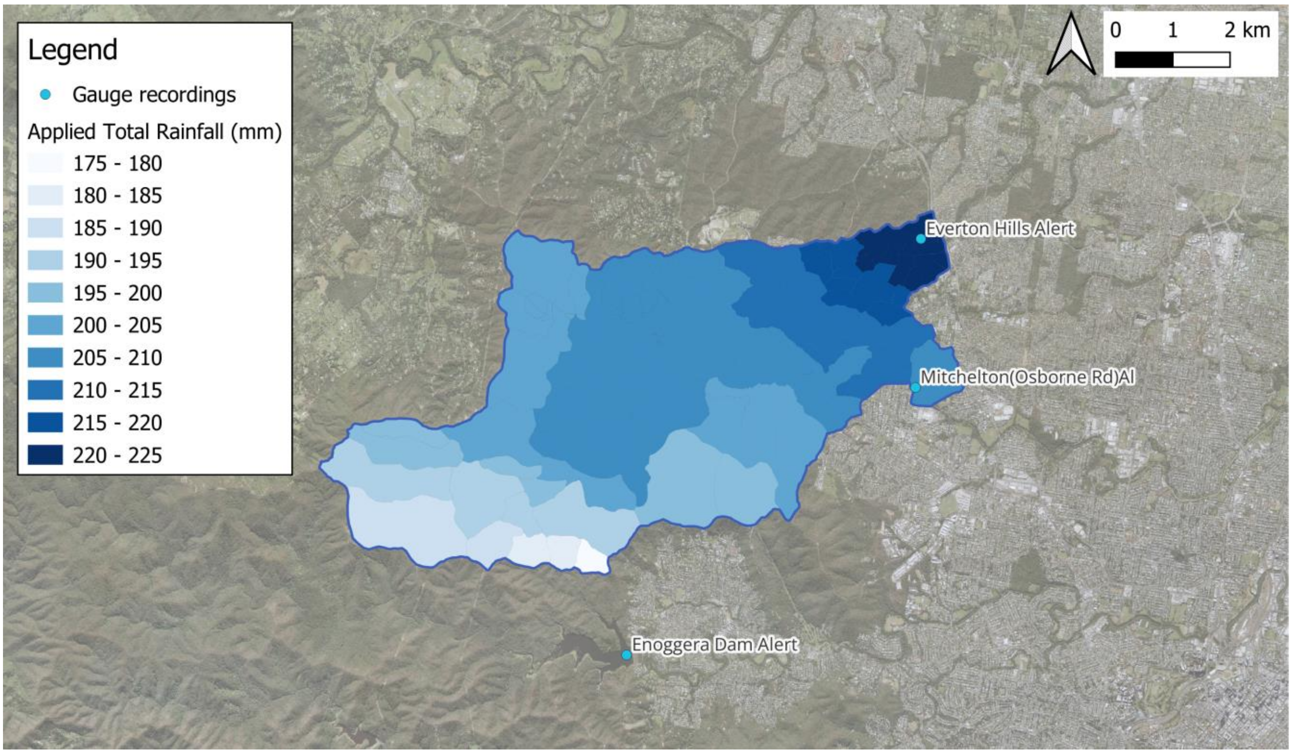



Figure A-3 BCC WBNM subcatchment rainfall totals – October 2010

Figure A-4 shows the recorded rainfall intensities and their estimated Annual Exceedance Probability (AEP) at the Everton Hills Alert and Mitchelton Alert rainfall stations for the October 2010 event. AEPs were estimated by comparing the recorded rainfalls to design rainfall intensities from the Bureau of Meteorology's Intensity-Frequency-Duration (IFD) rainfall data for storm durations of up to 96-hours.

For Everton Hills Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of less than 1 in 2;
- For storm durations of 6 hours, rainfall intensities had an AEP of less than 1 in 10 and
- Storm durations of 12 hours and longer had rainfall intensities with an AEP approximately 1 in 20.

For Mitchelton Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of approximately 1 in 2;
- For storm durations of 6 hours, rainfall intensities had an AEP of approximately 1 in 10 and
- Storm durations of 12 hours had rainfall intensities with an AEP of approximately 1 in 20.

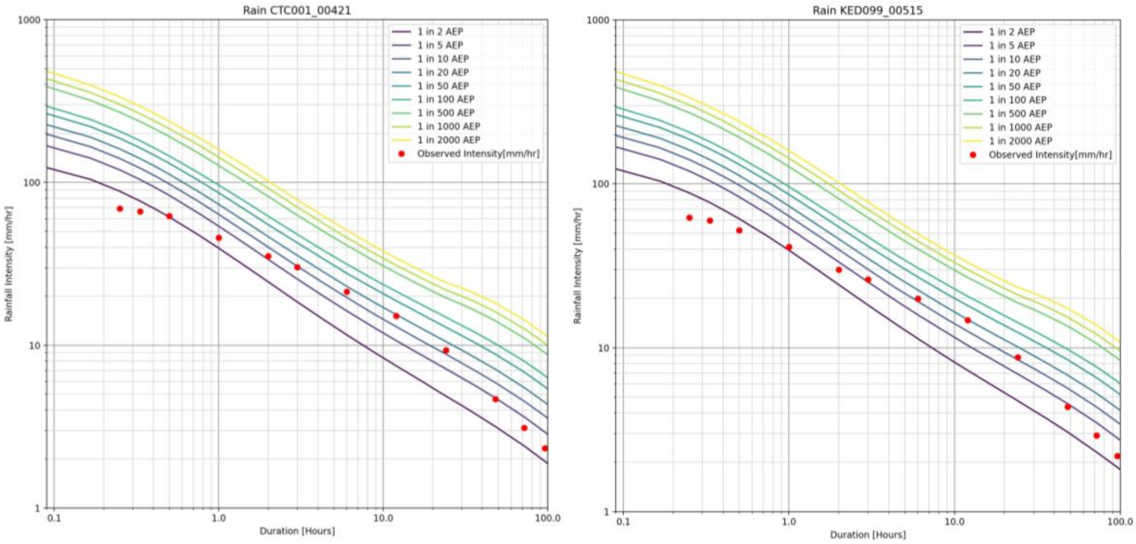



Figure A-4 Estimated AEP of the October 2010 event for Everton Hills Alert (left) and Mitchelton Alert (right)

## A-1-2 May 2015

Hydrological data from the rainfall stations at Enoggera Dam, Everton Hills, Mitchelton (Osborne Rd), Samford Village and Three Ways Alert were utilised to generate the spatial distribution of rainfall in the May 2015 event Figure A-5 and Figure A-6 present the cumulative and sub-daily rainfall plots for the Everton Hills and Mitchelton (Osborne Rd) Alert rainfall stations, respectively.

Rainfall was distributed using the standard WBNM method which assigns rainfall depths to each subcatchment based on a weighted average depth calculated using the nearest pluviograph station data. The weights are calculated based on the inverse square of the distance between the pluviography station and the sub-area centroid. Figure A-7 presents the spatial distribution of the total rainfalls across the modelled WBNM subcatchments. The event was very localised around the Mitchelton locality and rainfall total gradually reduced in a western direction.

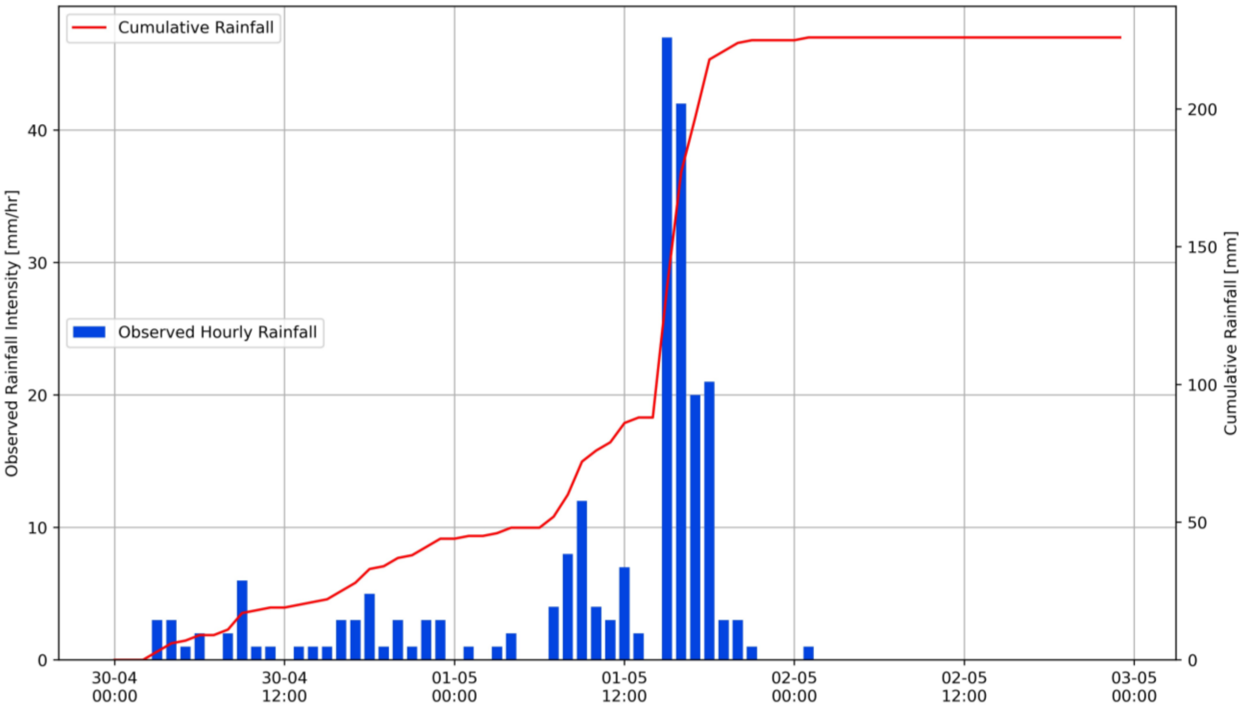



Figure A-5 Cumulative and sub-daily rainfall plot during the May 2015 event for Everton Hills Alert

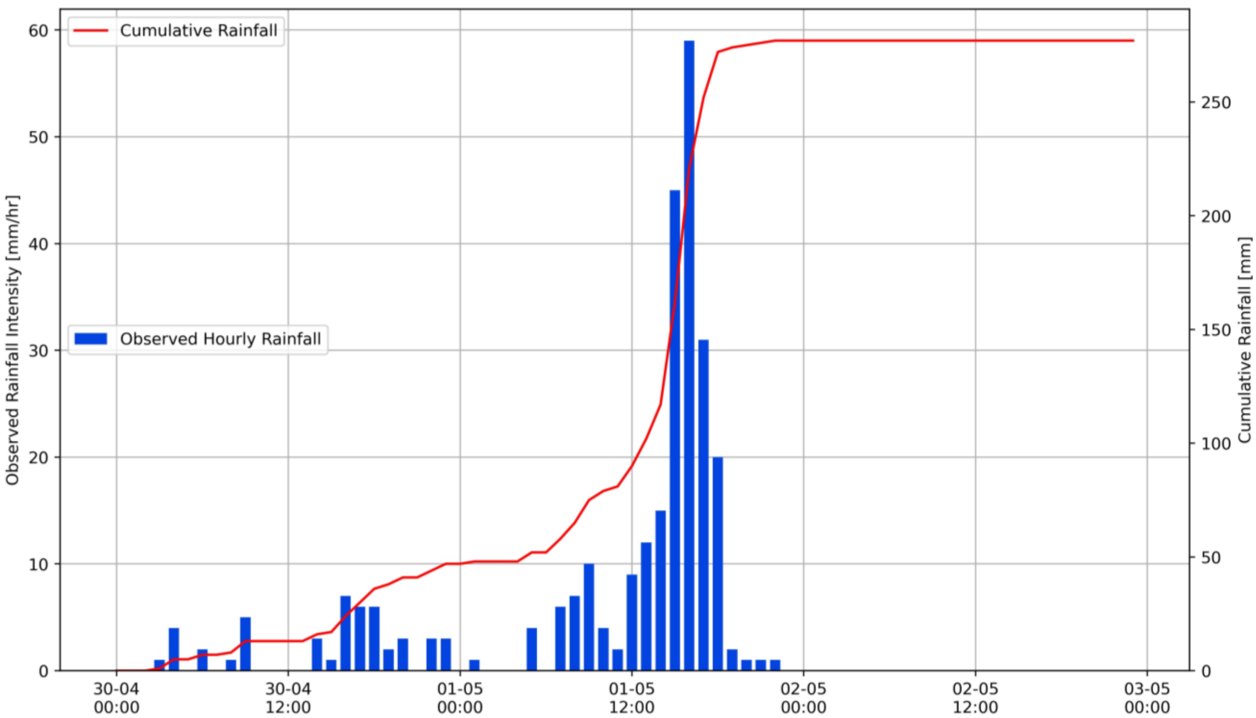



Figure A-6 Cumulative and sub-daily rainfall plot during the May 2015 event for Mitchelton Alert

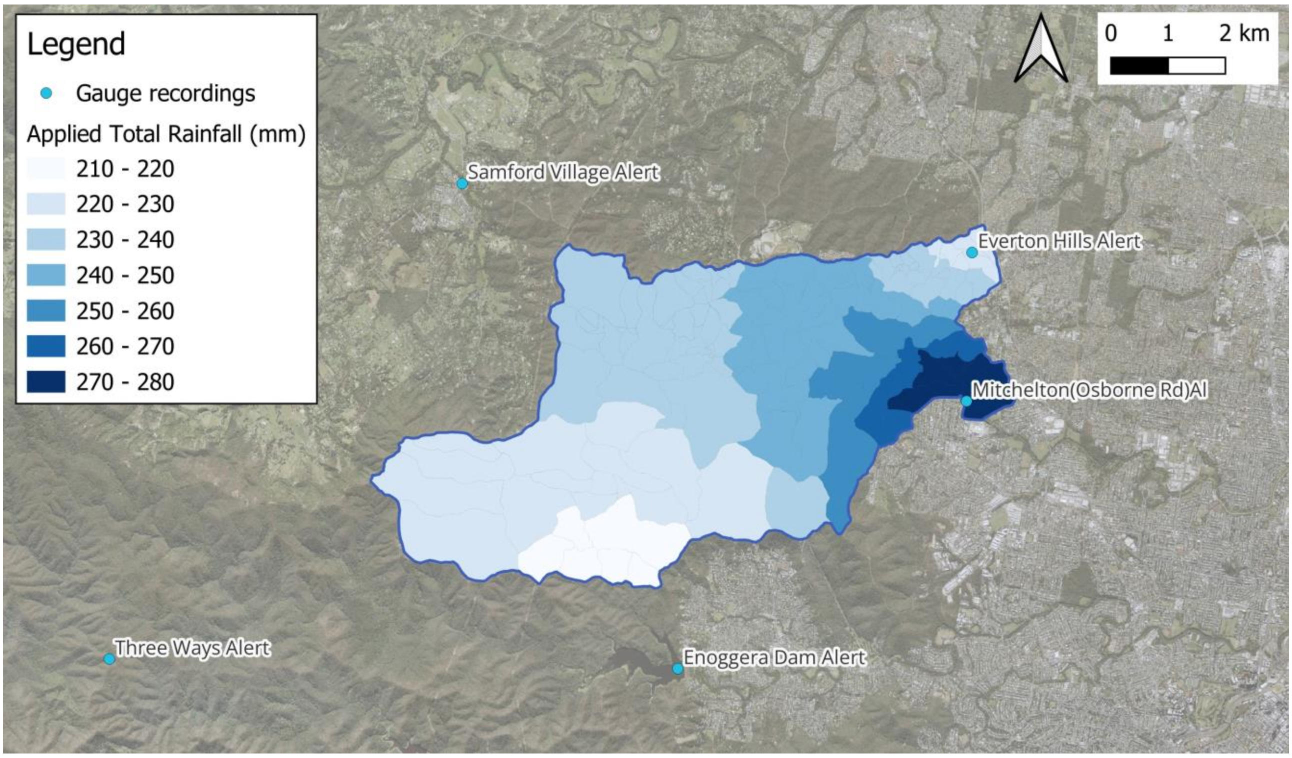



Figure A-7 BCC WBNM subcatchment rainfall totals – May 2015

Figure A-8 shows the recorded rainfall intensities and their estimated Annual Exceedance Probability (AEP) at the Everton Hills Alert and Mitchelton Alert rainfall stations for the May 2015 event. AEPs were estimated by comparing the recorded rainfalls to design rainfall intensities from the Bureau of Meteorology's Intensity-Frequency-Duration (IFD) rainfall data for storm durations of up to 96-hours.

For Everton Hills Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of approximately 1 in 5;
- For storm durations of 6 hours, rainfall intensities had an approximate AEP of 1 in 20 and
- Storm durations of 12 hours and longer had rainfall intensities with an AEP of less than 1 in 10.

For Mitchelton Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of approximately 1 in 10;
- For storm durations of 6 hours, rainfall intensities had an AEP of approximately 1 in 100 and
- Storm durations of 12 hours had rainfall intensities with an AEP of approximately 1 in 50.

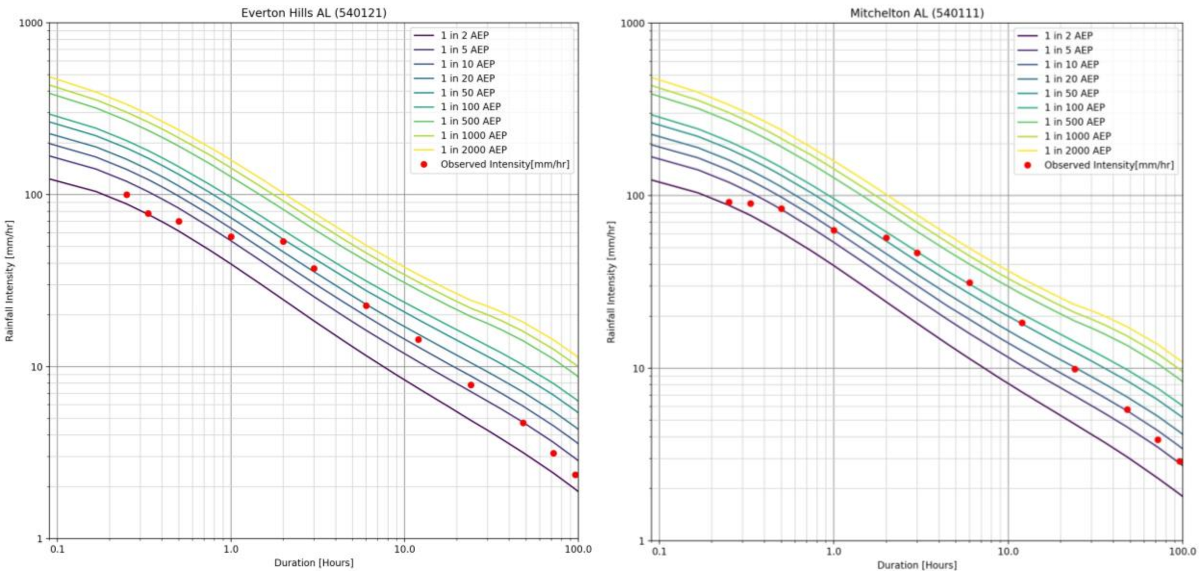



Figure A-8 Estimated AEP of the May 2015 event for Everton Hills Alert (left) and Mitchelton Alert (right)

## A-1-3 February 2022

Hydrological data from the rainfall stations at Enoggera Dam, Everton Hills, Mitchelton (Osborne Rd), Samford Village and Three Ways Alert were utilized to generate the spatial distribution of rainfall in the February 2022 event. Figure A-9 and Figure A-10 present the cumulative and sub-daily rainfall plots for the Everton Hills and Mitchelton (Osborne Rd) Alert rainfall stations, respectively.

Available information indicates that over 800 mm of rainfall occurred at each of the five analysed rainfall stations in the period 22 February to 1 March 2022. Hourly rainfall totals indicate that several storm events occurred during this period. The peak 1-hour bursts, which most of the flooding in the urbanised catchments would have been attributed to, occurred during the mid-afternoon of 27 February 2022. Figure A-11 presents the WBNM subcatchment spatial distribution of total rainfall for the event.

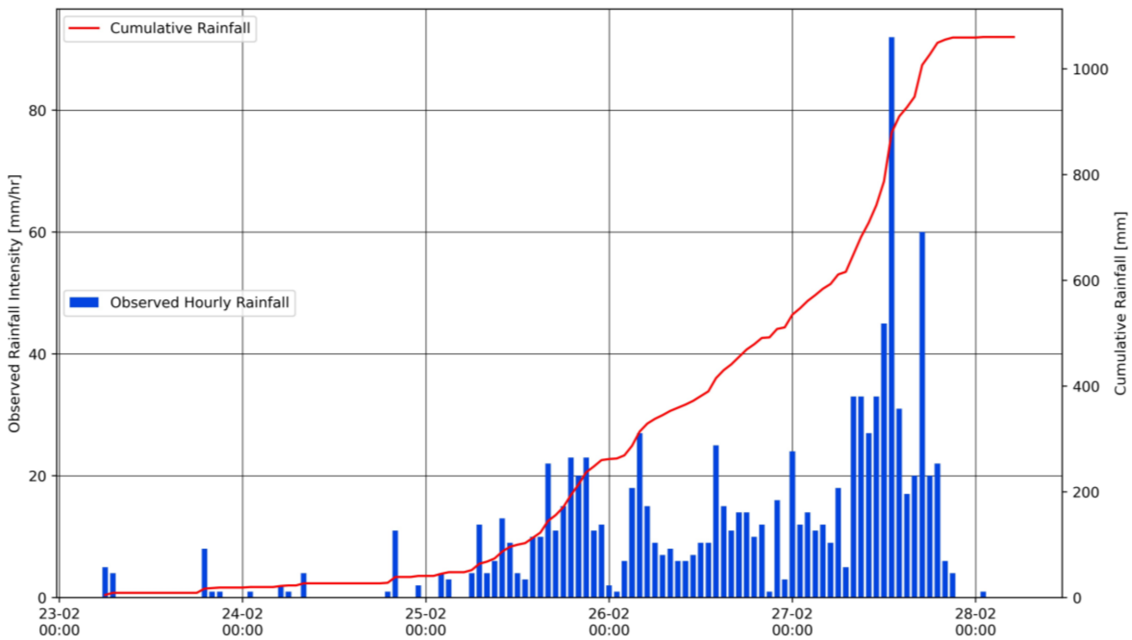



Figure A-9 Cumulative and sub-daily rainfall plot during the 2022 event for Everton Hills Alert

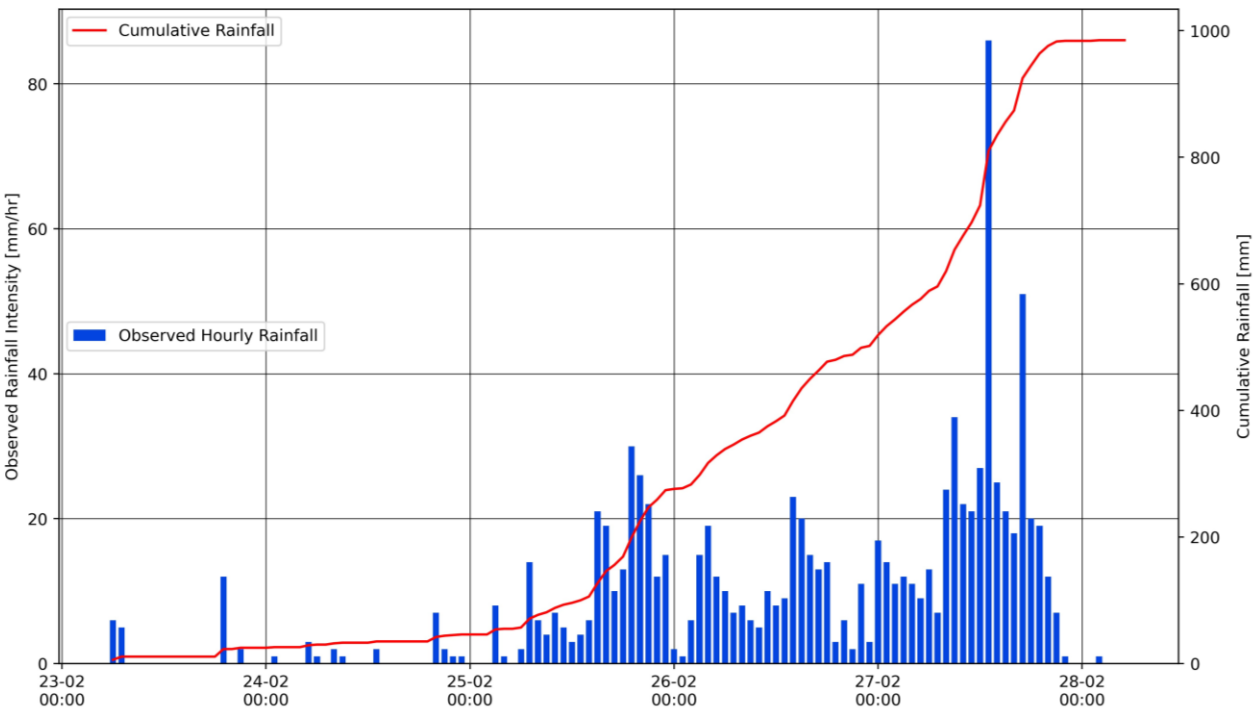



Figure A-10 Cumulative and sub-daily rainfall plot during the 2022 event for Mitchelton Alert

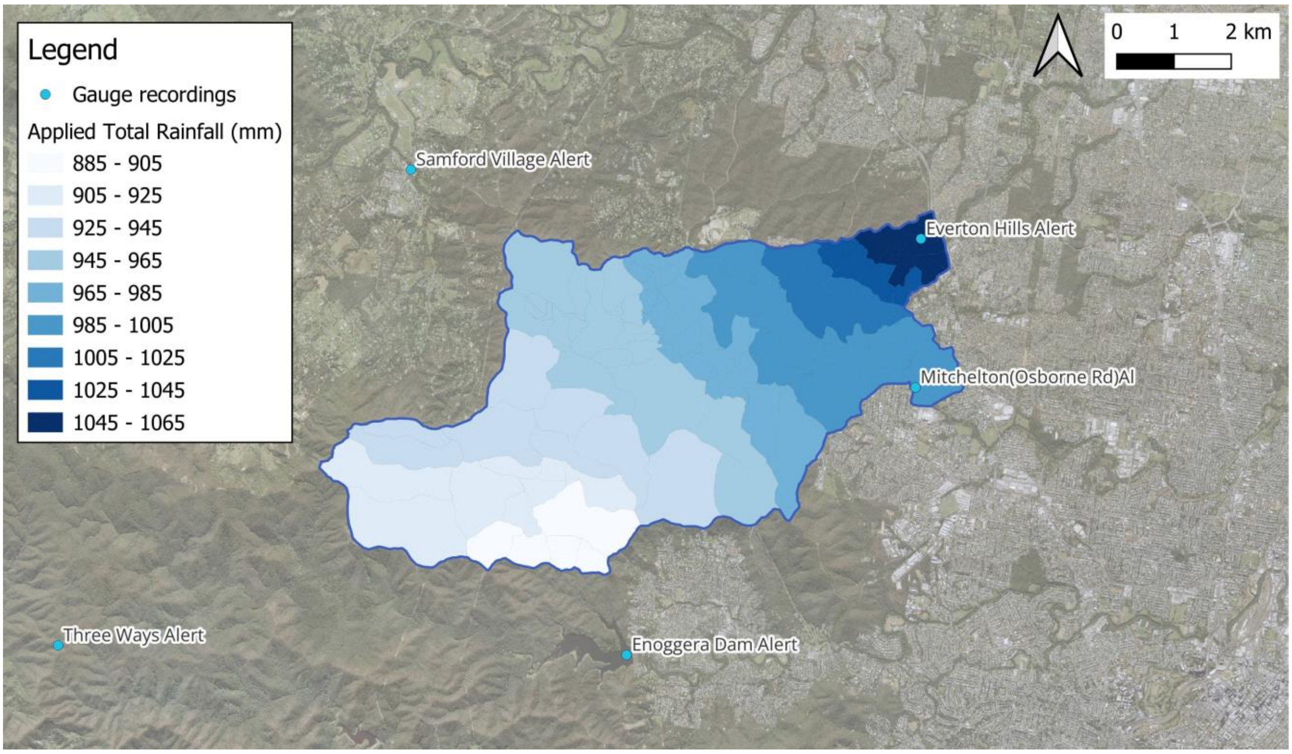



Figure A-11 BCC WBNM subcatchment rainfall totals – February 2022

Figure A-12 shows the recorded rainfall intensities for the February 2022 event and their estimated Annual Exceedance Probability (AEP) at the Everton Hills Alert and Mitchelton Alert rainfall stations. AEPs were estimated by comparing the recorded rainfalls to design rainfall intensities from the Bureau of Meteorology's Intensity-Frequency-Duration (IFD) rainfall data for storm durations of up to 96-hours.

For Everton Hills Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of approximately 1 in 100;
- For storm durations of 6 hours, rainfall intensities had an approximate AEP of 1 in 1000 and
- Storm durations of 12 hours and longer had rainfall intensities with an AEP of approximately 1 in 2000.

For Mitchelton Alert, the data indicates the following:

- Rainfall intensities for storm durations of 1 hour had an AEP of approximately 1 in 50;
- For storm durations of 6 hours, rainfall intensities had an AEP of approximately 1 in 500 and
- Storm durations of 12 hours had rainfall intensities with an AEP of less than 1 in 1000.

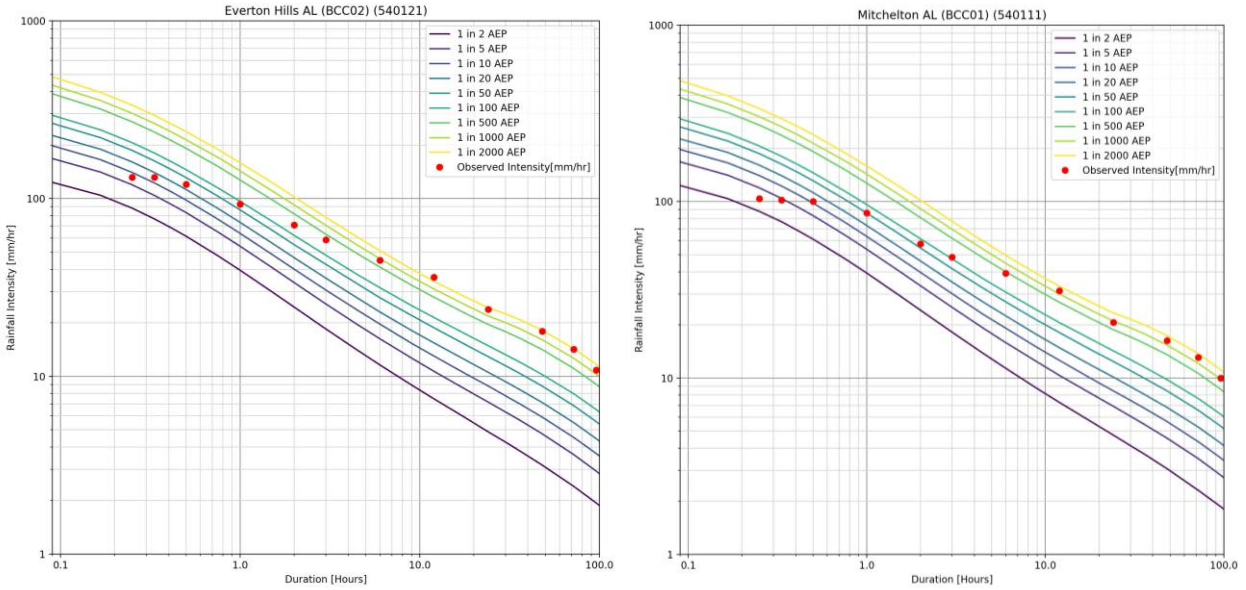



Figure A-12 Estimated AEP of February 2022 event for Everton Hills Alert (left) and Mitchelton Alert (right)

# APPENDIX B
# WBNM SUBCATCHMENT PROPERTIES

| WBNM Subcatchment ID | Area (ha) | Stage 2 hydrography Impervious (%) | Updated Current EIA (%) | Ultimate EIA (%) |
|---|---|---|---|---|
| KED043_00288 | 14.01 | 37.0 | 25.9 | 25.9 |
| KED043_00000 | 1.63 | 43.0 | 30.1 | 30.1 |
| KED019_01780 | 17.53 | 37.3 | 26.1 | 26.1 |
| KED021_00000 | 21.35 | 38.2 | 26.8 | 26.8 |
| KED019_01526 | 41.05 | 36.8 | 25.8 | 25.8 |
| KED019_01030 | 10.43 | 40.4 | 28.3 | 28.3 |
| KED027_00000 | 8.50 | 39.8 | 27.9 | 27.9 |
| KED025_00000 | 19.13 | 38.2 | 26.7 | 26.7 |
| KED019_00000 | 30.34 | 20.3 | 15.5 | 15.5 |
| KED032_00000 | 121.56 | 22.8 | 16.1 | 19.2 |
| KED030_00000 | 103.96 | 17.6 | 12.3 | 24.2 |
| KED028_01009 | 183.98 | 7.1 | 5.2 | 6.6 |
| KED028_00000 | 83.13 | 31.1 | 22.3 | 22.3 |
| KED012_00000 | 63.49 | 12.3 | 8.6 | 8.6 |
| KED010_00404 | 77.51 | 20.9 | 14.6 | 14.6 |
| KED010_00000 | 14.85 | 29.0 | 20.3 | 20.7 |
| KED008_00000 | 53.23 | 20.0 | 14.0 | 14.0 |
| KED026_00000 | 24.68 | 0.9 | 0.6 | 0.6 |
| KED024_01180 | 28.97 | 1.1 | 0.8 | 0.8 |
| KED024_00000 | 127.25 | 11 | 7.7 | 7.7 |
| KED022_00000 | 34.94 | 1.4 | 1 | 1.0 |
| KED020_01128 | 51.01 | 1.2 | 0.8 | 0.8 |
| KED020_00000 | 31.35 | 0.2 | 0.2 | 0.2 |
| KED018_00000 | 136.21 | 0.6 | 0.4 | 0.4 |
| KED016_02714 | 193.89 | 1.3 | 0.9 | 0.9 |
| KED016_00868 | 108.82 | 2.6 | 2 | 2.0 |
| KED016_00000 | 25.32 | 4.6 | 3.2 | 3.2 |
| KED014_00000 | 26.33 | 3.7 | 2.6 | 2.6 |
| KED006_00000 | 42.42 | 0.5 | 0.4 | 0.4 |
| KED004_07551 | 84.04 | 1.6 | 1.1 | 1.1 |
| KED004_05168 | 122.41 | 2.7 | 1.9 | 1.9 |
| KED004_04498 | 16.05 | 22.4 | 15.7 | 15.7 |
| KED004_04260 | 6.36 | 30.1 | 21.2 | 21.2 |
| KED004_03281 | 48.1 | 20.9 | 14.7 | 14.7 |
| KED004_02038 | 116.73 | 27.4 | 19.2 | 19.6 |

| WBNM Subcatchment ID | Area (ha) | Stage 2 hydrography Impervious (%) | Updated Current EIA (%) | Ultimate EIA (%) |
|---|---|---|---|---|
| KED004_00000 | 175.30 | 25.0 | 17.7 | 17.7 |
| KED009_00227 | 9.65 | 1.5 | 1.0 | 1.3 |
| KED009_00000 | 2.36 | 30.0 | 21.0 | 21.0 |
| KED007_00155 | 42.01 | 0.8 | 0.5 | 0.6 |
| KED007_00000 | 2.91 | 10.5 | 7.4 | 8.0 |
| KED023_00125 | 122.76 | 0.3 | 0.2 | 0.3 |
| KED023_00000 | 1.27 | 10.9 | 7.6 | 8.5 |
| KED047_00000 | 5.93 | 0.0 | 0.0 | 0.0 |
| KED003_00076 | 7.05 | 0.0 | 0.0 | 0.0 |
| KED003_00000 | 3.99 | 7.2 | 5.0 | 5.4 |
| KED001_09351 | 120.86 | 1.4 | 1.0 | 1.2 |
| KED001_08904 | 40.68 | 4.2 | 3.0 | 3.3 |
| KED001_08568 | 22.27 | 4.2 | 2.9 | 3.1 |
| KED001_08279 | 8.87 | 14 | 9.8 | 9.8 |
| KED005_00166 | 23.83 | 0.4 | 0.3 | 0.4 |
| KED005_00000 | 1.35 | 20.9 | 16.8 | 16.8 |
| KED001_07620 | 69.63 | 15.9 | 11.1 | 11.1 |
| KED001_07159 | 16.82 | 10.6 | 7.4 | 9.4 |
| KED041_00000 | 15.91 | 16.7 | 11.7 | 12.7 |
| KED001_06761 | 5.03 | 14.5 | 10.1 | 18.6 |
| KED011_00000 | 1.37 | 19.0 | 13.3 | 13.3 |
| KED001_06786 | 15.66 | 33.0 | 23.1 | 24.4 |
| KED001_06654 | 0.55 | 0.7 | 0.5 | 0.5 |
| KED013_00574 | 17.32 | 22.7 | 15.9 | 17.6 |
| KED015_00000 | 10.33 | 29.7 | 20.8 | 21.7 |
| KED013_00058 | 15.35 | 35.1 | 24.6 | 24.6 |
| KED013_00000 | 0.45 | 20.1 | 14.1 | 14.1 |
| KED002_00628 | 18.74 | 24.5 | 17.1 | 17.1 |
| KED002_00000 | 17.43 | 40.1 | 28.1 | 28.1 |
| KED001_06340 | 5.51 | 41.4 | 29.0 | 29.0 |
| KED001_06162 | 2.62 | 49.8 | 34.9 | 38.4 |
| KED017_00000 | 21.19 | 39 | 27.3 | 27.3 |
| KED001_06052 | 2.29 | 38.4 | 26.9 | 29.2 |
| KED001_05445 | 17.27 | 33.8 | 23.6 | 24.0 |
| KED001_04318 | 17.25 | 8.2 | 5.9 | 5.9 |

| WBNM Subcatchment ID | Area (ha) | Stage 2 hydrography Impervious (%) | Updated Current EIA (%) | Ultimate EIA (%) |
|---|---|---|---|---|
| KED001_03053 | 67.94 | 16.0 | 11.5 | 11.5 |
| KED001_02532 | 15.02 | 18.4 | 12.9 | 12.9 |
| KED001_02211 | 11.31 | 22.6 | 16.5 | 20.9 |
| KED045_00170 | 37.67 | 37.6 | 26.9 | 27.5 |
| KED031_00000 | 4.28 | 42.4 | 29.7 | 30.8 |
| KED029_00674 | 12.92 | 38.4 | 26.9 | 26.9 |
| KED029_00000 | 19.18 | 40.8 | 31.1 | 39.4 |
| KED001_01923 | 9.02 | 52.2 | 48.1 | 48.1 |
| KED001_01760 | 8.22 | 24.5 | 17.1 | 17.1 |
| KED033_00000 | 31.01 | 35.9 | 25.3 | 27.0 |
| KED045_00000 | 5.90 | 59.9 | 49.3 | 55.7 |
| KED001_01456 | 10.55 | 30.0 | 21.0 | 21.0 |
| KED035_00000 | 25.94 | 38.3 | 26.8 | 26.8 |
| KED001_00979 | 10.08 | 22.0 | 15.4 | 15.4 |
| KED036_00000 | 60.10 | 31.1 | 22.1 | 22.1 |
| KED001_00105 | 27.20 | 20.8 | 14.6 | 14.6 |
| KED034_01376 | 26.08 | 35.3 | 24.7 | 24.7 |
| KED034_00000 | 40.08 | 33.8 | 24 | 24.0 |
| KED001_00000 | 1.14 | 4.1 | 2.8 | 3.6 |
| KED049_00000 | 13.32 | 27.3 | 19.1 | 19.1 |
| KED037_01214 | 10.55 | 43.6 | 30.5 | 30.5 |
| KED039_00000 | 21.56 | 39.9 | 28.3 | 28.3 |
| KED037_00874 | 9.05 | 41.8 | 29.3 | 29.3 |
| KED037_00000 | 9.90 | 40.2 | 28.1 | 28.1 |
| KED099_00786 | 16.47 | 30.0 | 13.5 | 13.5 |
| KED099_00515 | 5.20 | 21.0 | 12.4 | 12.4 |
| KED099_00000 | 58.08 | 20.0 | 12.3 | 12.3 |
| CTC015_00000 | 8.89 | 16.7 | 11.7 | 11.7 |
| CTC028_00000 | 5.96 | 39.3 | 27.5 | 32.1 |
| CTC026_00610 | 10.35 | 40.2 | 33.9 | 39.9 |
| CTC026_00250 | 17.51 | 36.7 | 25.8 | 30.0 |
| CTC026_00000 | 9.73 | 25.0 | 17.5 | 17.5 |
| CTC022_00985 | 8.13 | 53.0 | 50.0 | 57.8 |
| CTC024_00000 | 8.86 | 52.0 | 47.2 | 54.6 |
| CTC022_00304 | 15.08 | 25.2 | 17.7 | 22.4 |

| WBNM Subcatchment ID | Area (ha) | Stage 2 hydrography Impervious (%) | Updated Current EIA (%) | Ultimate EIA (%) |
|---|---|---|---|---|
| CTC022_00000 | 5.71 | 27.4 | 19.2 | 19.2 |
| CTC020_00990 | 18.11 | 22.9 | 16.1 | 23.9 |
| CTC020_00420 | 19.15 | 32.9 | 23 | 25.0 |
| CTC020_00250 | 3.04 | 13.2 | 9.2 | 22.8 |
| CTC020_00000 | 5.39 | 20.8 | 14.5 | 20.4 |
| CTC017_00000 | 4.44 | 8.8 | 6.2 | 6.3 |
| CTC004_00875 | 10.40 | 33.5 | 23.5 | 23.5 |
| CTC006_00000 | 25.45 | 29.8 | 20.9 | 21.2 |
| CTC004_00461 | 13.86 | 31.5 | 22.1 | 22.2 |
| CTC004_00075 | 15.55 | 28.1 | 19.7 | 19.7 |
| CTC004_00000 | 0.57 | 22.4 | 15.6 | 15.6 |
| CTC002_00000 | 8.23 | 37.0 | 25.9 | 32.2 |
| CTC008_00000 | 4.86 | 20.9 | 14.6 | 16.6 |
| CTC001_06870 | 11.94 | 5.4 | 3.8 | 4.2 |
| CTC001_06706 | 5.19 | 25.8 | 18.1 | 18.1 |
| CTC003_00000 | 12.10 | 7.2 | 5.0 | 5.2 |
| CTC001_06506 | 4.32 | 29.3 | 20.5 | 20.5 |
| CTC001_06344 | 3.40 | 28.8 | 20.2 | 20.2 |
| CTC001_06047 | 9.02 | 29.4 | 20.6 | 20.6 |
| CTC001_05331 | 25.23 | 31.8 | 22.2 | 22.4 |
| CTC001_04377 | 35.65 | 33.0 | 23.1 | 23.6 |
| CTC001_03980 | 23.16 | 30.5 | 21.4 | 21.8 |
| CTC001_03740 | 13.32 | 19.5 | 13.6 | 15.0 |
| CTC010_00000 | 14.80 | 19.5 | 13.8 | 29.2 |
| CTC001_03080 | 18.09 | 30.7 | 21.6 | 23.0 |
| CTC012_00000 | 12.91 | 44.5 | 38.1 | 51.8 |
| CTC007_00000 | 6.93 | 40.7 | 28.5 | 28.5 |
| CTC005_00406 | 11.74 | 40.2 | 28.2 | 28.2 |
| CTC005_00176 | 3.31 | 47.3 | 33.1 | 37.2 |
| CTC005_00000 | 9.46 | 38.9 | 27.2 | 27.2 |
| CTC001_02666 | 6.11 | 19.2 | 13.4 | 17.0 |
| CTC009_00000 | 10.02 | 38.7 | 27.1 | 27.1 |
| CTC014_00000 | 5.52 | 36.9 | 34.7 | 34.7 |
| CTC001_02374 | 4.95 | 31.3 | 21.9 | 22.1 |
| CTC001_02047 | 12.21 | 29.7 | 20.8 | 24.6 |

| WBNM Subcatchment ID | Area (ha) | Stage 2 hydrography Impervious (%) | Updated Current EIA (%) | Ultimate EIA (%) |
|---|---|---|---|---|
| CTC001_01960 | 0.60 | 8.1 | 5.7 | 5.7 |
| CTC016_00510 | 13.15 | 23.6 | 17.1 | 24.1 |
| CTC016_00400 | 9.42 | 35.0 | 27.2 | 31.0 |
| CTC016_00000 | 13.34 | 30.0 | 21 | 22.5 |
| CTC001_01880 | 0.77 | 27.3 | 19.1 | 19.1 |
| CTC001_01777 | 1.58 | 22.1 | 15.5 | 17.3 |
| CTC011_00000 | 4.29 | 9.6 | 7.2 | 7.2 |
| CTC001_01565 | 1.79 | 15.0 | 10.5 | 10.5 |
| CTC018_00000 | 7.21 | 31.0 | 21.7 | 32.1 |
| CTC001_01137 | 17.34 | 13.7 | 9.6 | 16.7 |
| CTC001_01041 | 7.39 | 9.7 | 6.8 | 6.8 |
| CTC001_00883 | 0.86 | 14.5 | 10.2 | 10.2 |
| CTC001_00697 | 9.03 | 34.3 | 24 | 24.0 |
| CTC001_00530 | 1.07 | 4.5 | 3.2 | 3.2 |
| CTC013_00000 | 8.14 | 14.4 | 10.0 | 10.0 |
| CTC001_00421 | 0.72 | 0.8 | 0.6 | 0.6 |
| CTC001_00116 | 1.72 | 11.5 | 8.1 | 8.1 |
| CTC001_00000 | 6.00 | 45.6 | 31.9 | 31.9 |

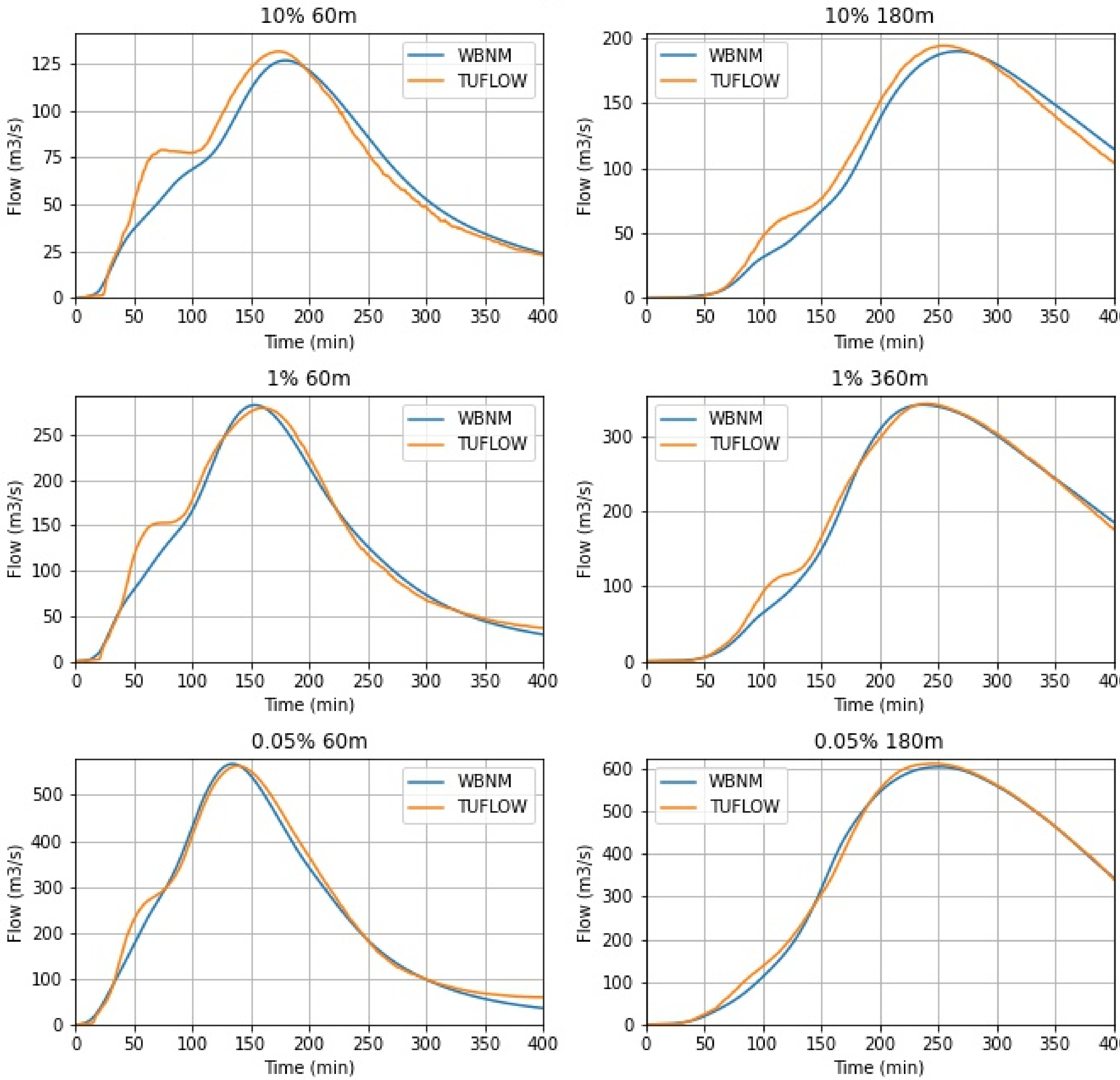
# APPENDIX C
# HEH PLOTS AND SUMMARY TABLES

| POI | Artificial Storage Required? | Storage description | HEH criteria met? | Justification if criteria not met |
|---|---|---|---|---|
| CTC001_00116 | ✓ | Floodplain storage along banks of Cabbage Tree Creek | ✗ | Good match in peaks (5/6 events within 4%). Good match in peak timing diff (5/6 events within 11 minutes). All NSE values over 0.96 with good match of shape. |
| CTC001_00697 | ✗ | | ✓ | — |
| CTC001_01137 | ✗ | | ✓ | — |
| CTC001_03080 | ✗ | | ✗ | Reasonable match on peaks (4/6 events within 10%). Excellent match in peak timing diff (all events within 8 minutes). Unable to replicate rising limb well although all NSE over 0.87. |
| CTC001_03980 | ✗ | | ✗ | Good match in peaks (5/6 events within 10%). All peak timing differences within 6 minutes. All NSE values over 0.93 with reasonable match of shape. |
| CTC001_04377 | ✗ | | ✗ | Good match in peaks (5/6 events within 10%). Good match in peak timing difference (all within 9 minutes) |
| CTC001_05331 | ✗ | | ✗ | Good match in peaks (5/6 events within 10%). Excellent match in peak timing difference (all within 4 minutes). All NSE above 0.92 and good match in shape. |
| CTC001_06344 | ✗ | | ✓ | — |

| POI | Artificial Storage Required? | Storage description | HEH criteria met? | Justification if criteria not met |
|---|---|---|---|---|
| CTC004_00461 | ✘ | | ✘ | Good match in peaks (5/6 events within 10%). Excellent match in peak timing difference (all within 6 minutes). All NSE above 0.97 and excellent match in shape. |
| KED001_00979 | ✘ | | ✘ | Excellent match in peaks (All events within 5%). Good match in peak timing difference (5/6 within 10 minutes). All NSE above 0.97 and good match in shape. |
| KED001_01923 | ✘ | | ✘ | Excellent match in peaks (All events within 3%). Good match in peak timing difference (5/6 within 10 minutes). All NSE above 0.99 and excellent match in shape. |
| KED001_04318 | ✓ | Floodplain storage along banks of Kedron Brook, Keperra golf club | ✘ | Excellent match in peaks (All events within 5%). Reasonable match in peak timing difference (4/6 within 15 minutes). All NSE above 0.99 and excellent match in shape. |
| KED001_05445 | ✘ | | ✓ | — |
| KED001_07159 | ✘ | | ✓ | — |
| KED004_00000 | ✓ | Floodplain storage upstream of Samford Road | ✘ | Good match in peaks (4/6 events within 10%). Good match in peak timing difference (5/6 within 15 minutes). |
| KED019_01030 | ✓ | Ferny Hills upstream detention basin (George Wilmore park) | ✘ | Good match in peaks (5/6 events within 8%). Good match in peak timing difference (5/6 within 15 minutes). |

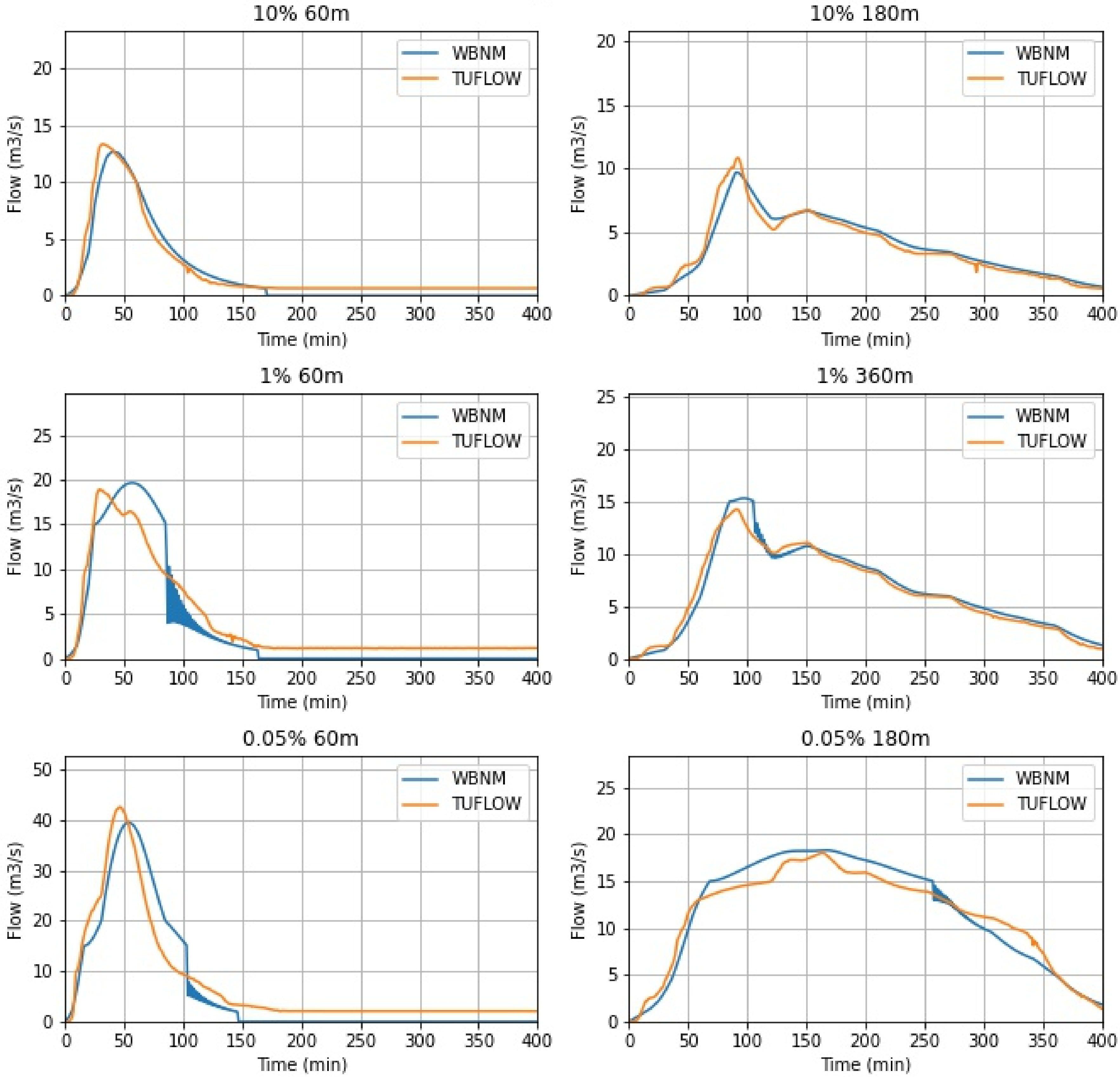
| POI | Artificial Storage Required? | Storage description | HEH criteria met? | Justification if criteria not met |
|---|---|---|---|---|
| KED099_00786 | ✗ | | ✓ | — |

# KED099_00786



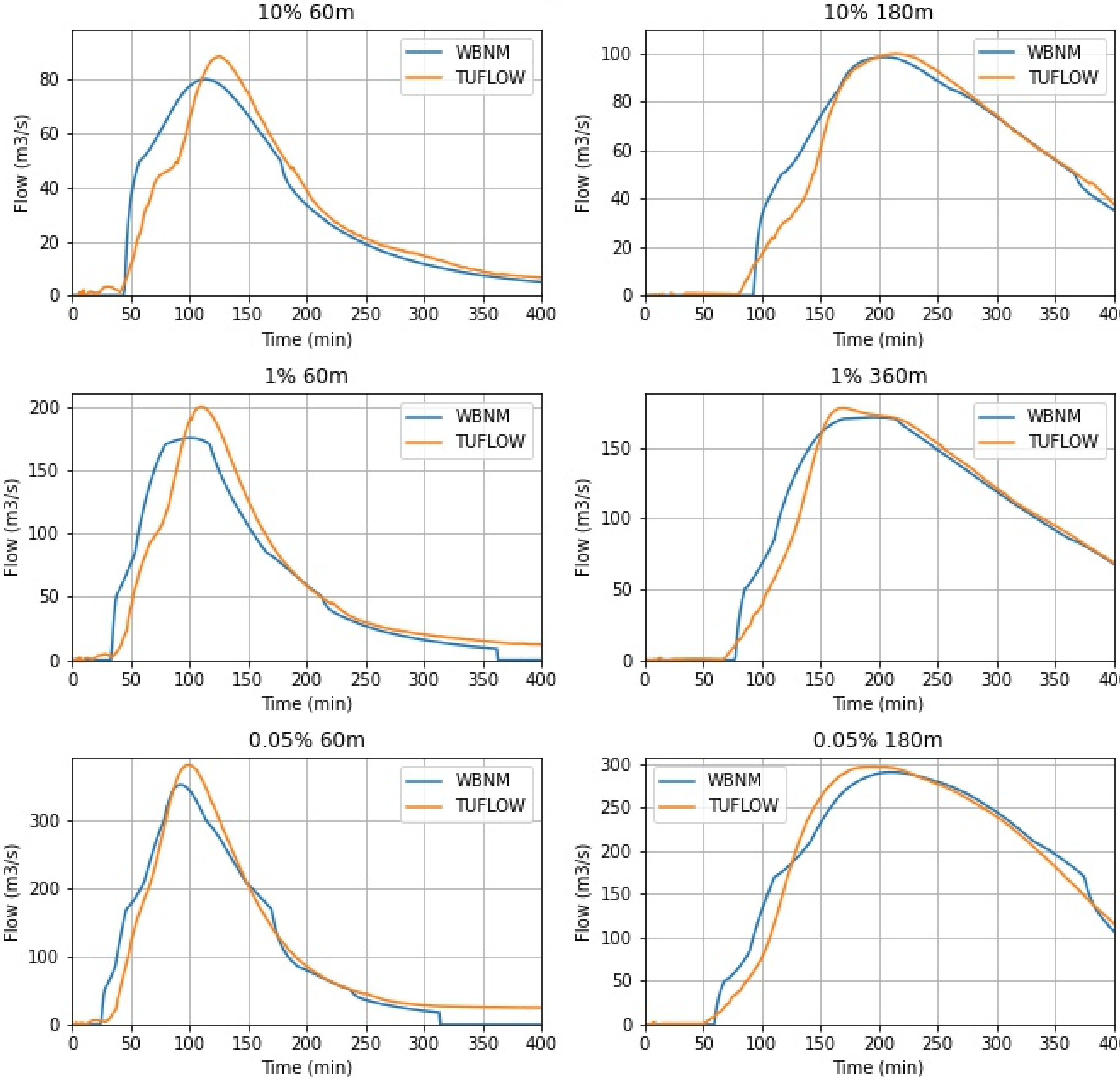

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 3.75% | 6.0min | 0.92 |
| 10% 180m | 2.3% | 11.0min | 0.98 |
| 1% 60m | 1.14% | 7.0min | 0.97 |
| 1% 360m | 0.52% | 3.0min | 0.99 |
| 0.05% 60m | 0.79% | 4.0min | 0.99 |
| 0.05% 180m | 1.24% | 7.0min | 1.0 |

# KED019_01030



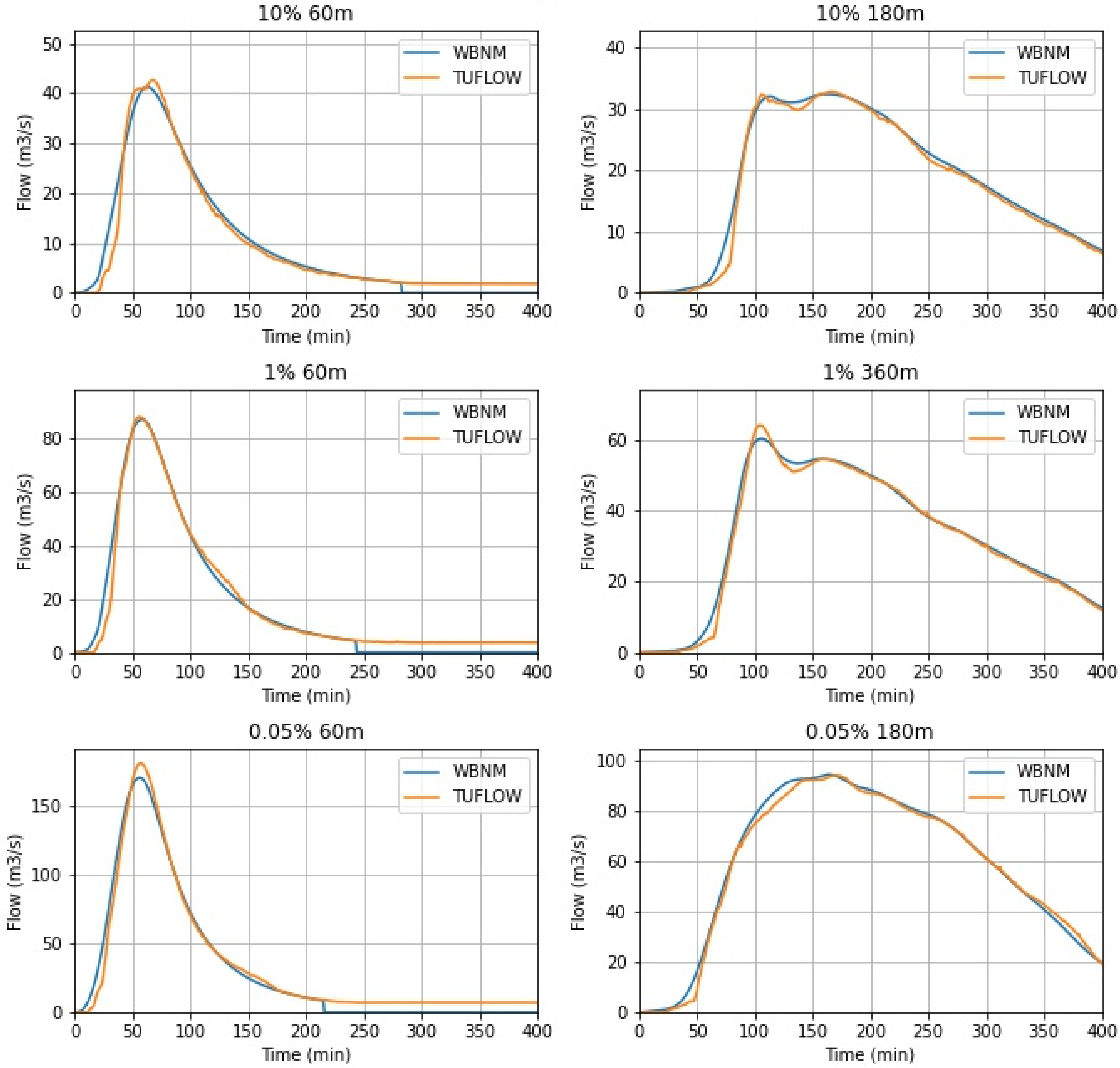

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 5.37% | 10.0min | 0.95 |
| 10% 180m | 11.82% | 1.0min | 0.94 |
| 1% 60m | 3.75% | 28.0min | 0.84 |
| 1% 360m | 6.82% | 6.0min | 0.95 |
| 0.05% 60m | 7.86% | 7.0min | 0.87 |
| 0.05% 180m | 1.64% | 2.0min | 0.91 |

KED004_00000



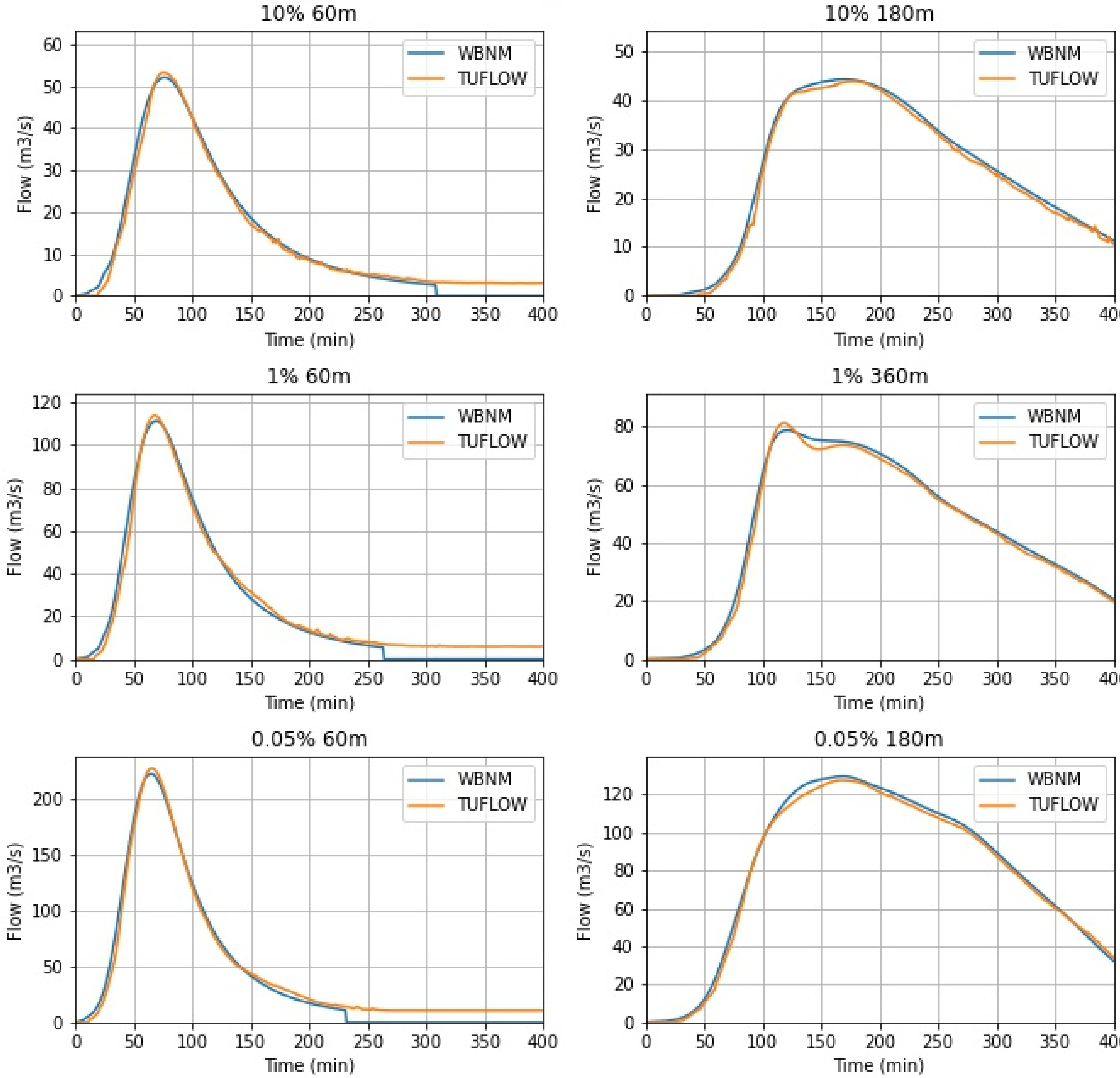

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 10.62% | 11.0min | 0.87 |
| 10% 180m | 1.39% | 9.0min | 0.95 |
| 1% 60m | 14.25% | 9.0min | 0.87 |
| 1% 360m | 3.93% | 25.0min | 0.96 |
| 0.05% 60m | 8.3% | 6.0min | 0.95 |
| 0.05% 180m | 2.09% | 13.0min | 0.97 |

# KED001_07159



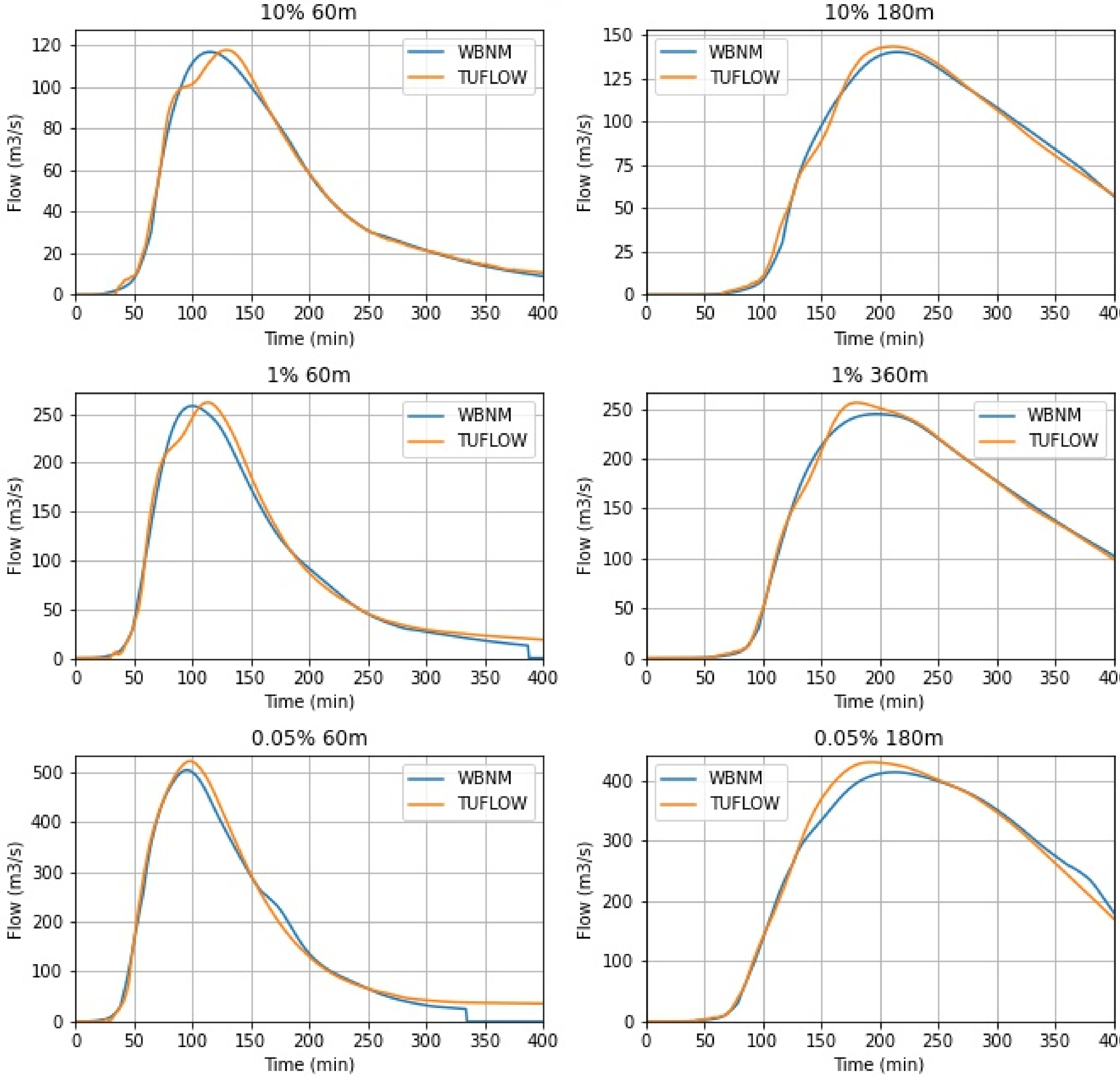

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 3.24% | 5.0min | 0.97 |
| 10% 180m | 1.37% | 3.0min | 0.99 |
| 1% 60m | 1.12% | 2.0min | 0.98 |
| 1% 360m | 6.25% | 2.0min | 0.99 |
| 0.05% 60m | 6.22% | 0.0min | 0.98 |
| 0.05% 180m | 0.34% | 7.0min | 0.99 |

# KED001_05445



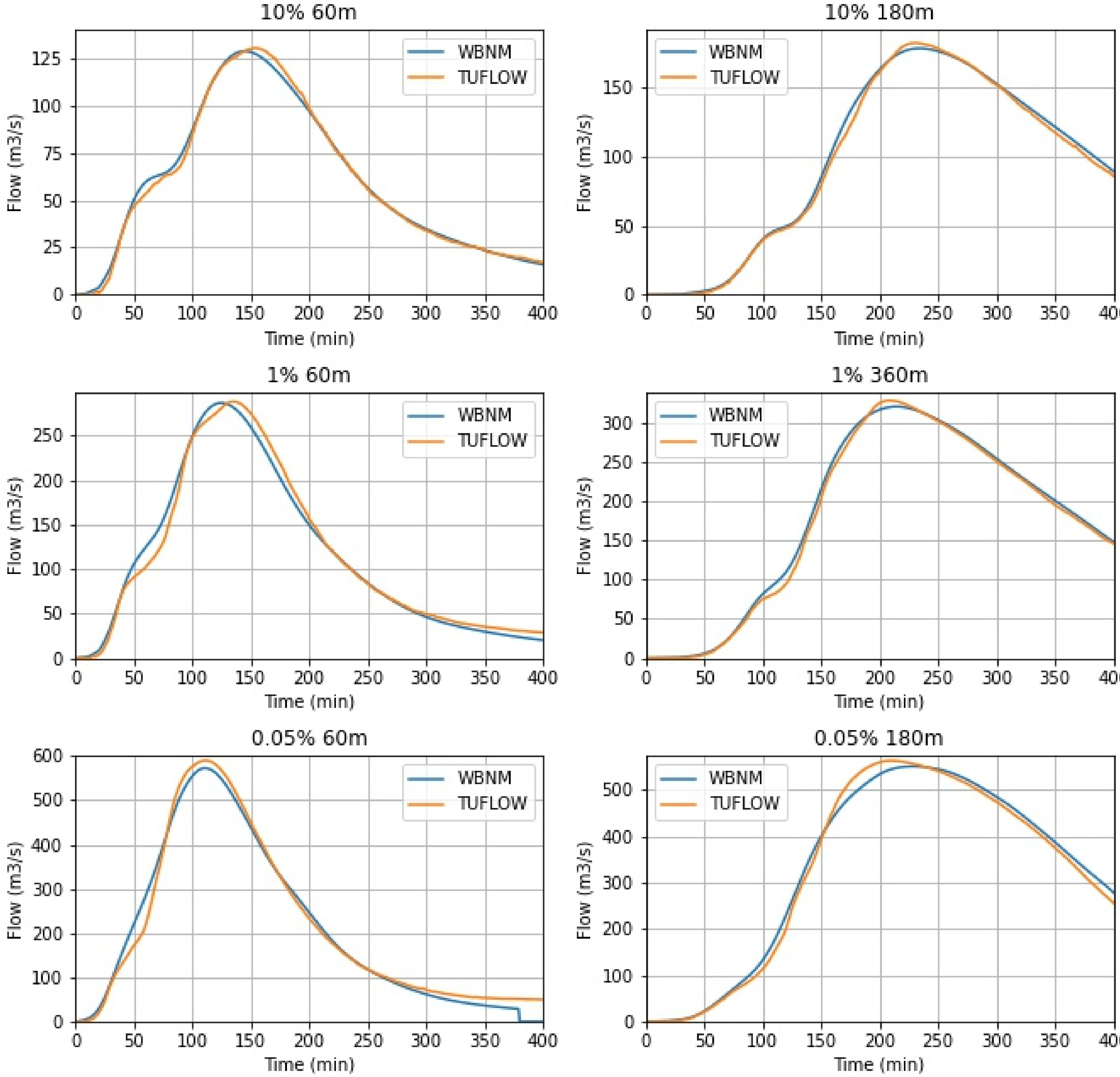

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 2.24% | 0.0min | 0.99 |
| 10% 180m | 0.94% | 9.0min | 1.0 |
| 1% 60m | 2.4% | 1.0min | 0.99 |
| 1% 360m | 3.17% | 4.0min | 1.0 |
| 0.05% 60m | 2.26% | 0.0min | 0.99 |
| 0.05% 180m | 1.65% | 1.0min | 1.0 |

# KED001_04318



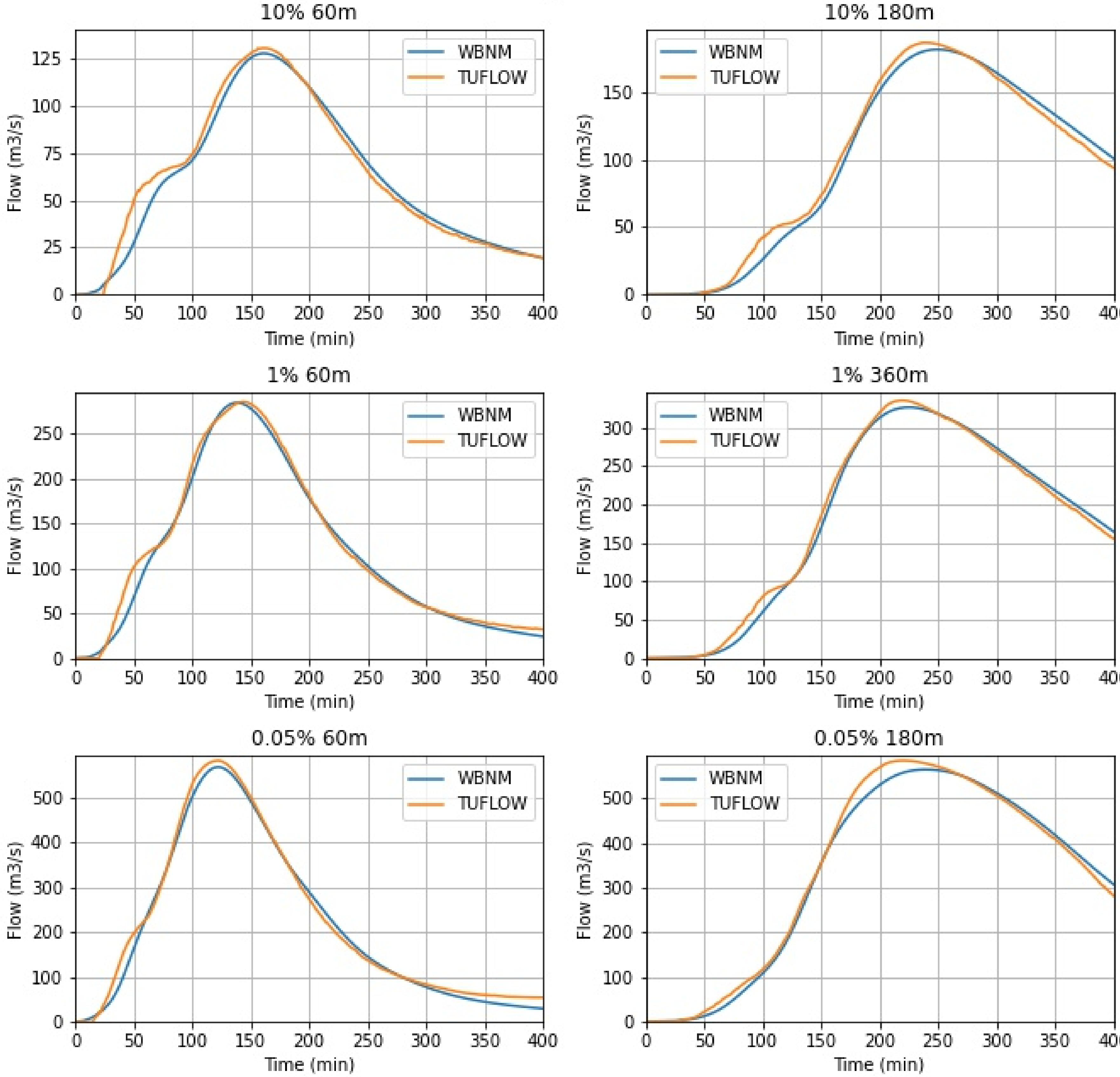

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 0.79% | 15.0min | 0.99 |
| 10% 180m | 2.26% | 3.0min | 1.0 |
| 1% 60m | 1.39% | 14.0min | 0.99 |
| 1% 360m | 4.71% | 18.0min | 1.0 |
| 0.05% 60m | 3.6% | 3.0min | 0.99 |
| 0.05% 180m | 4.06% | 21.0min | 0.99 |

KED001_01923



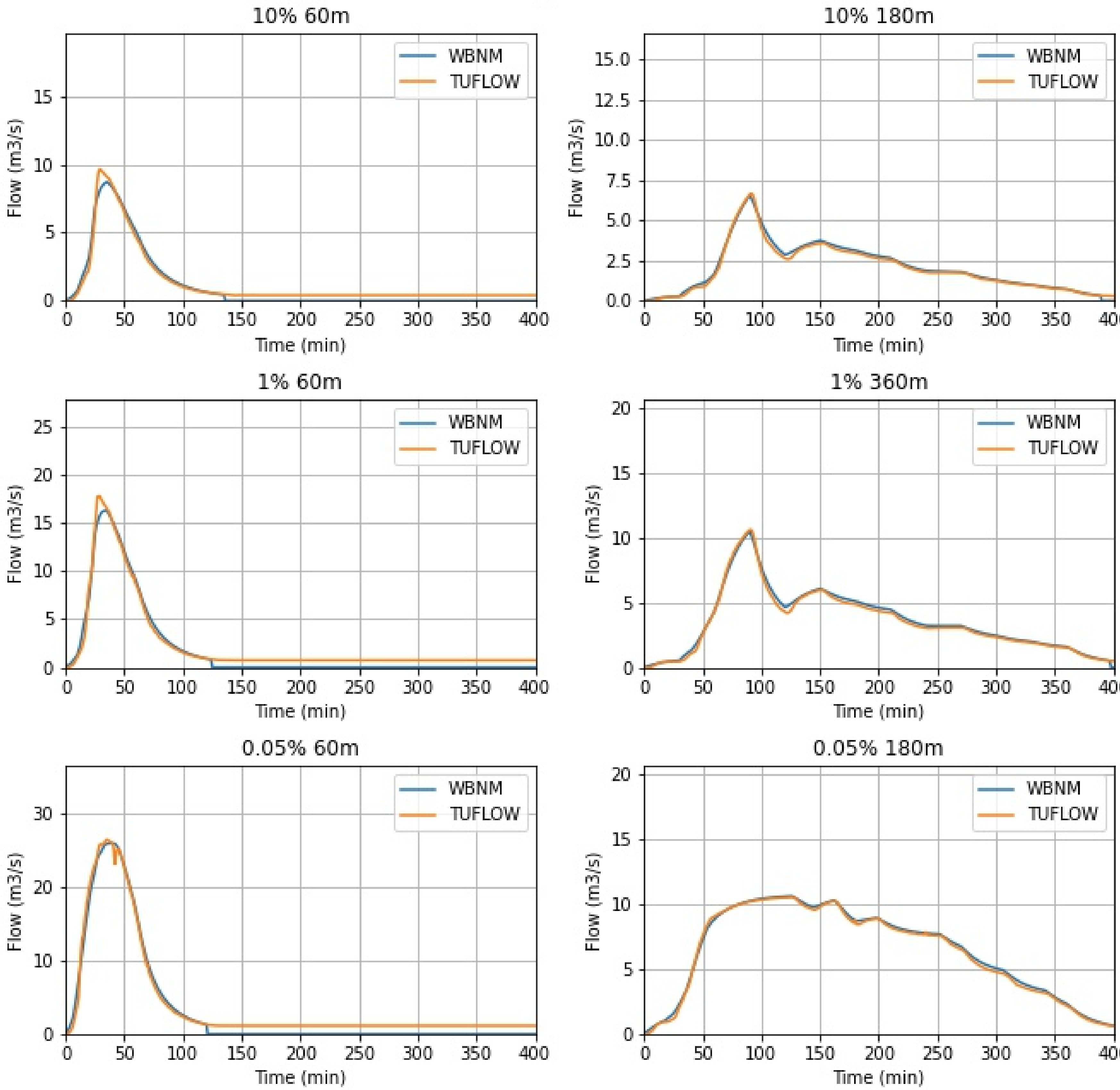

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 1.23% | 9.0min | 1.0 |
| 10% 180m | 2.16% | 3.0min | 1.0 |
| 1% 60m | 0.52% | 10.0min | 0.99 |
| 1% 360m | 2.38% | 5.0min | 1.0 |
| 0.05% 60m | 2.98% | 0.0min | 0.99 |
| 0.05% 180m | 2.2% | 18.0min | 1.0 |

# KED001_00979



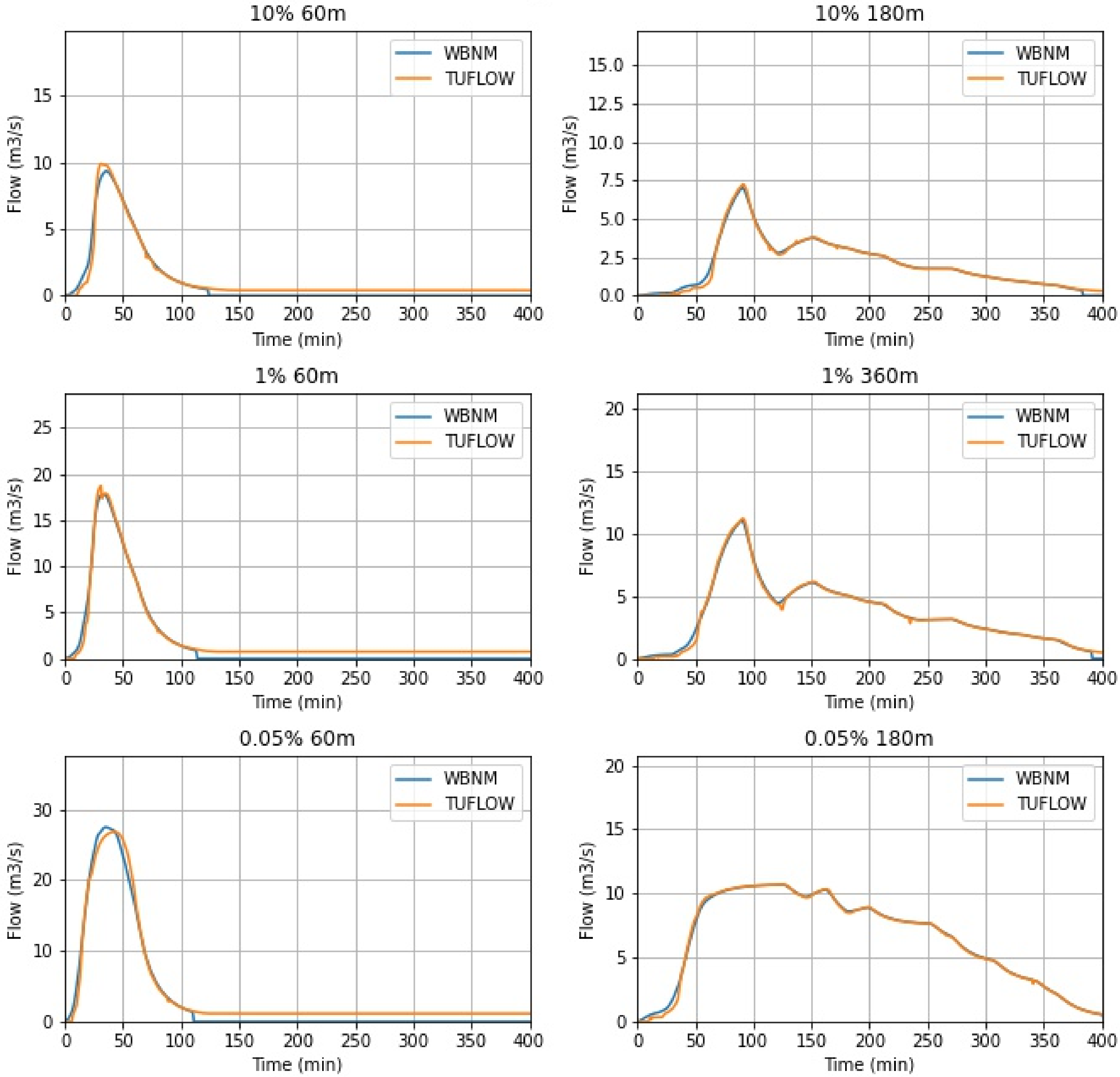

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 2.16% | 1.0min | 0.97 |
| 10% 180m | 2.73% | 9.0min | 0.99 |
| 1% 60m | 0.41% | 5.0min | 0.99 |
| 1% 360m | 2.75% | 6.0min | 1.0 |
| 0.05% 60m | 2.54% | 1.0min | 0.99 |
| 0.05% 180m | 3.55% | 19.0min | 0.99 |

# CTC004_00461



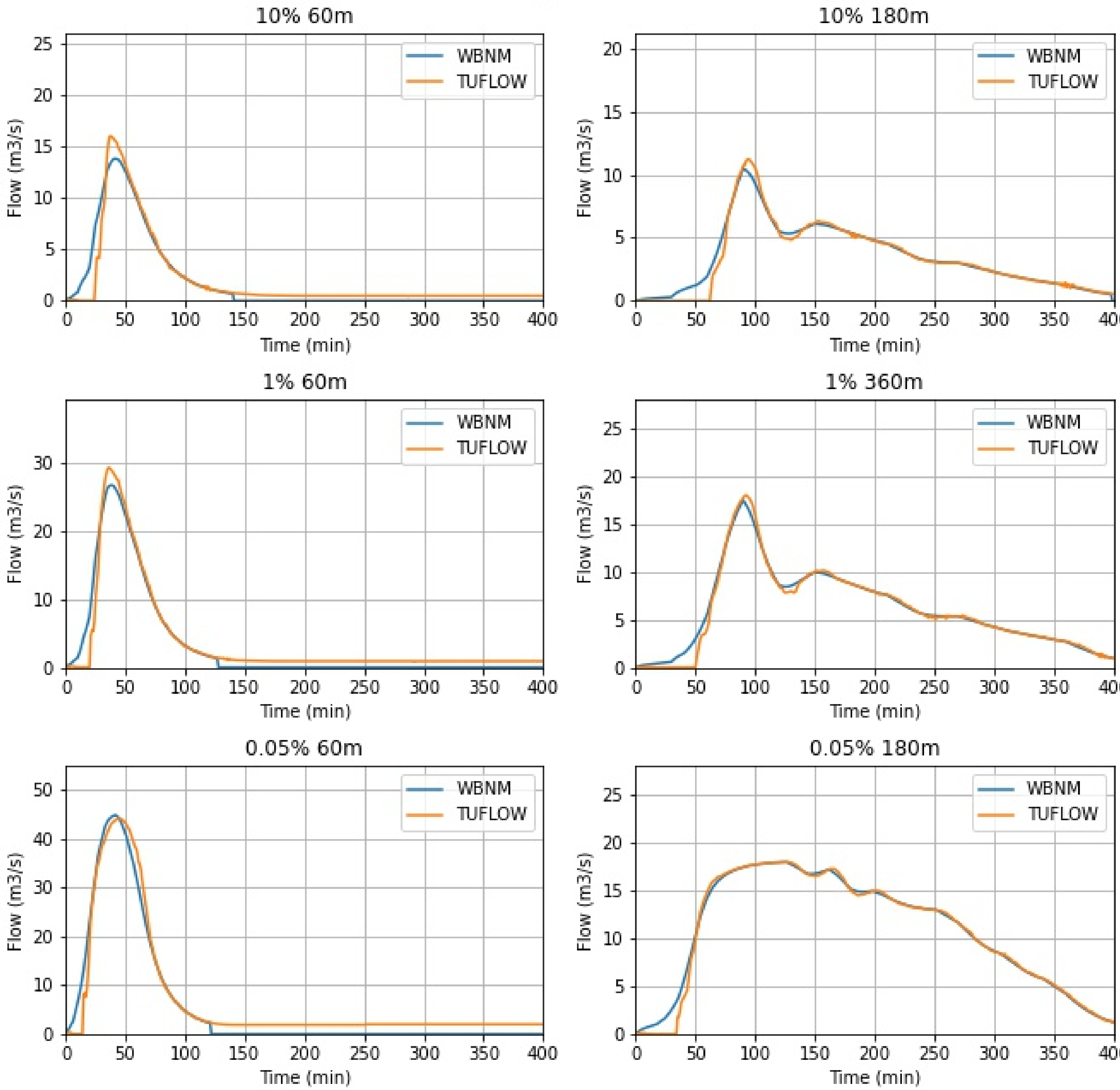

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 10.51% | 6.0min | 0.97 |
| 10% 180m | 1.83% | 1.0min | 0.99 |
| 1% 60m | 9.11% | 6.0min | 0.98 |
| 1% 360m | 1.19% | 1.0min | 0.99 |
| 0.05% 60m | 2.01% | 3.0min | 0.98 |
| 0.05% 180m | 0.86% | 0.0min | 1.0 |

## CTC001_06344

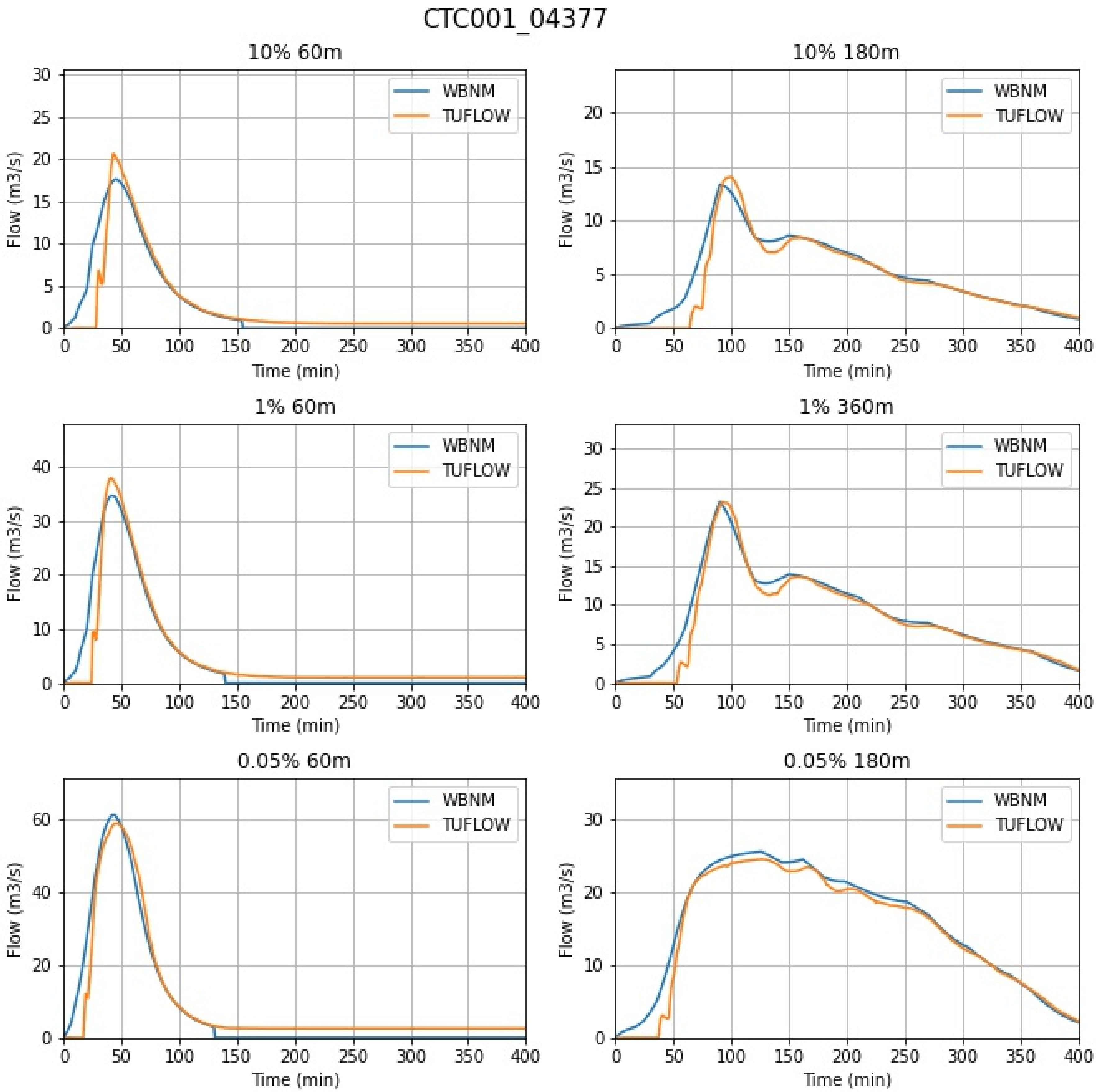



| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 5.92% | 5.0min | 0.97 |
| 10% 180m | 3.13% | 1.0min | 0.99 |
| 1% 60m | 5.32% | 2.0min | 0.98 |
| 1% 360m | 1.31% | 1.0min | 0.99 |
| 0.05% 60m | 2.43% | 8.0min | 0.98 |
| 0.05% 180m | 0.01% | 0.0min | 1.0 |

# CTC001_05331

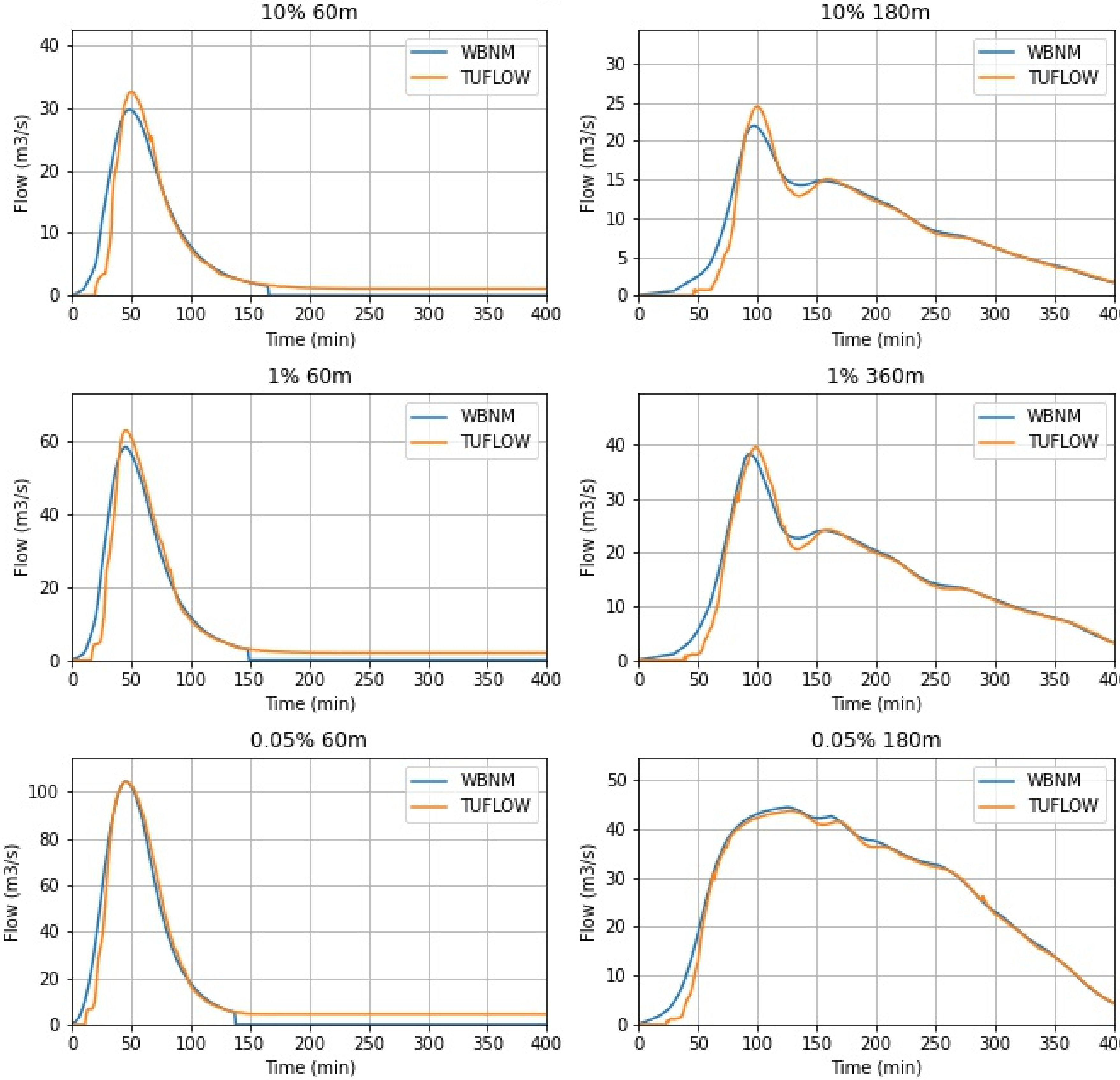



| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 15.99% | 4.0min | 0.92 |
| 10% 180m | 7.13% | 4.0min | 0.96 |
| 1% 60m | 9.62% | 2.0min | 0.96 |
| 1% 360m | 2.84% | 2.0min | 0.98 |
| 0.05% 60m | 1.61% | 3.0min | 0.96 |
| 0.05% 180m | 0.08% | 0.0min | 0.99 |



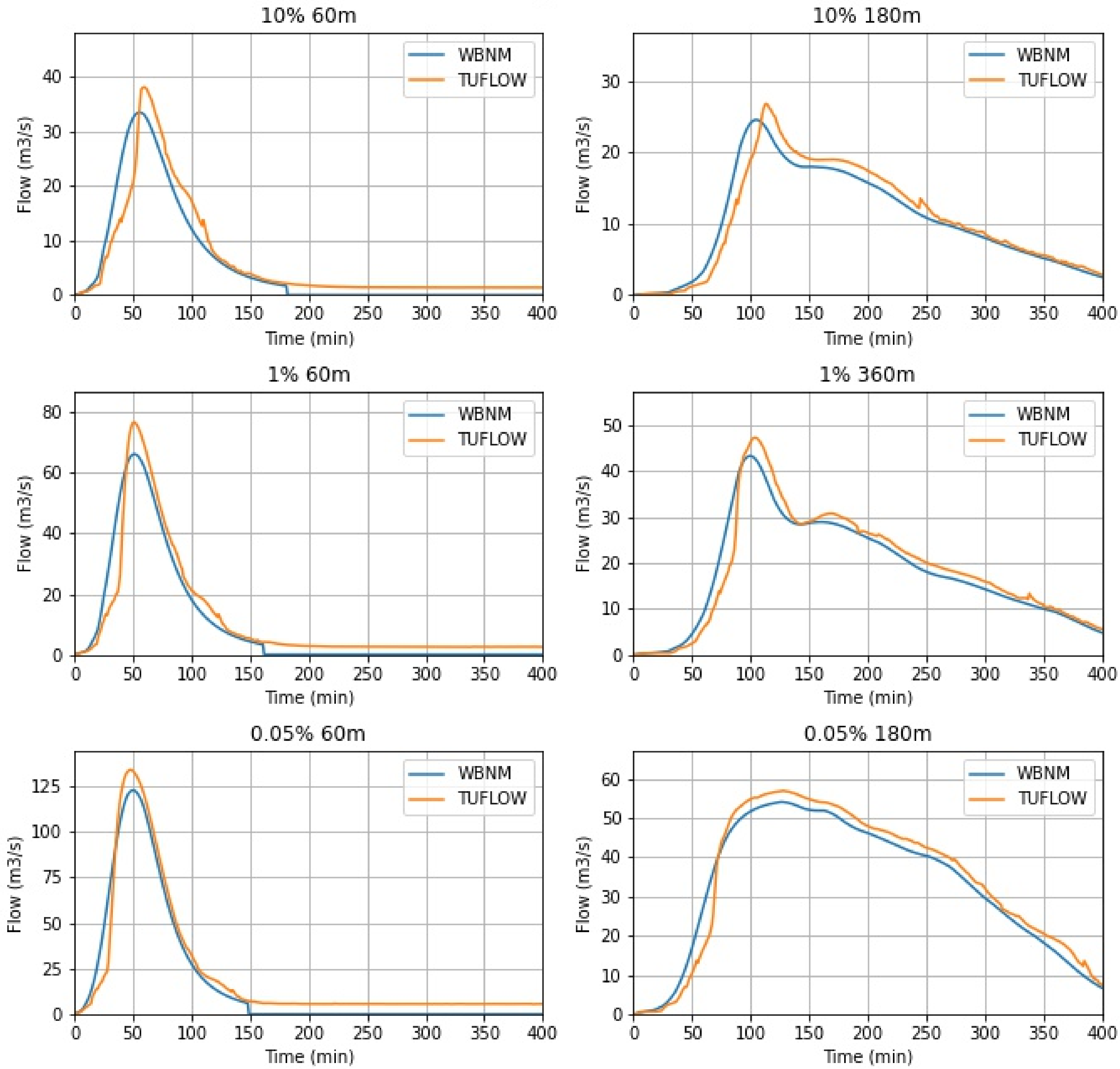

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 17.02% | 2.0min | 0.83 |
| 10% 180m | 5.19% | 9.0min | 0.89 |
| 1% 60m | 9.57% | 1.0min | 0.9 |
| 1% 360m | 0.07% | 2.0min | 0.94 |
| 0.05% 60m | 3.83% | 4.0min | 0.94 |
| 0.05% 180m | 3.97% | 1.0min | 0.96 |

CTC001_03980



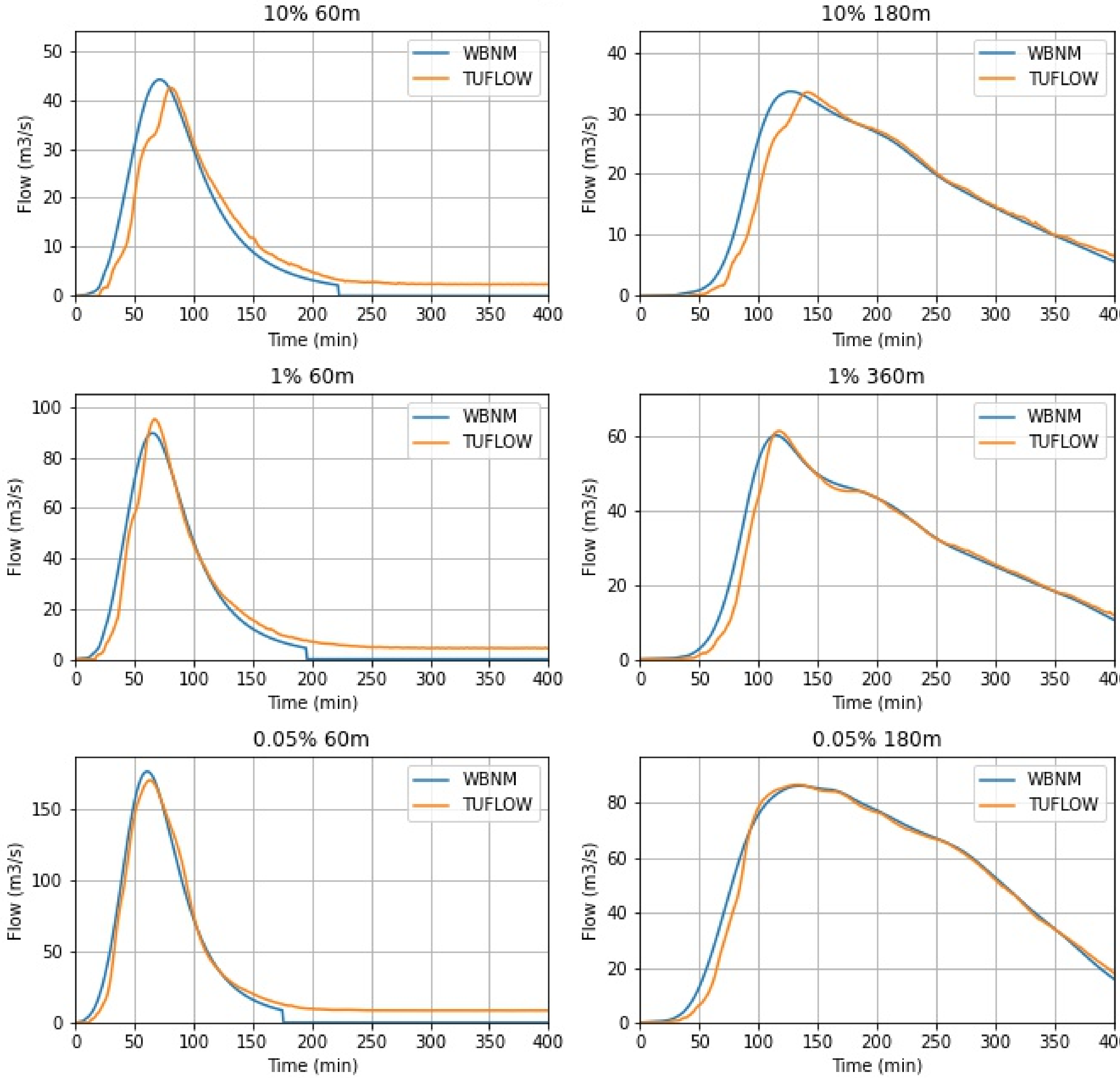

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 9.43% | 2.0min | 0.93 |
| 10% 180m | 11.26% | 3.0min | 0.95 |
| 1% 60m | 7.88% | 1.0min | 0.95 |
| 1% 360m | 3.23% | 6.0min | 0.97 |
| 0.05% 60m | 0.06% | 0.0min | 0.96 |
| 0.05% 180m | 1.87% | 2.0min | 0.98 |

## CTC001_03080



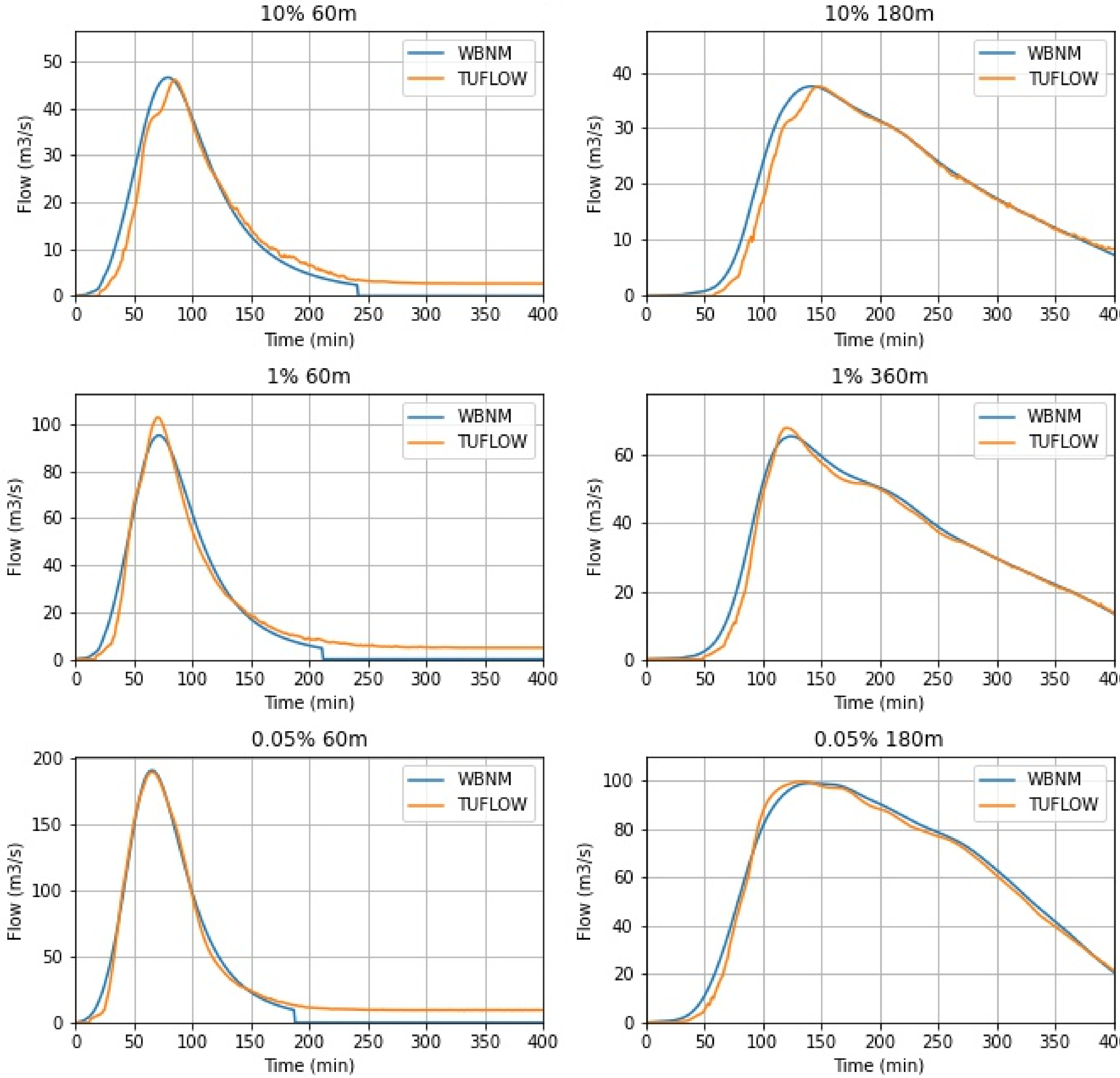

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 13.86% | 4.0min | 0.87 |
| 10% 180m | 9.17% | 8.0min | 0.92 |
| 1% 60m | 15.92% | 0.0min | 0.91 |
| 1% 360m | 9.16% | 4.0min | 0.93 |
| 0.05% 60m | 9.17% | 2.0min | 0.96 |
| 0.05% 180m | 5.26% | 2.0min | 0.96 |

CTC001_01137



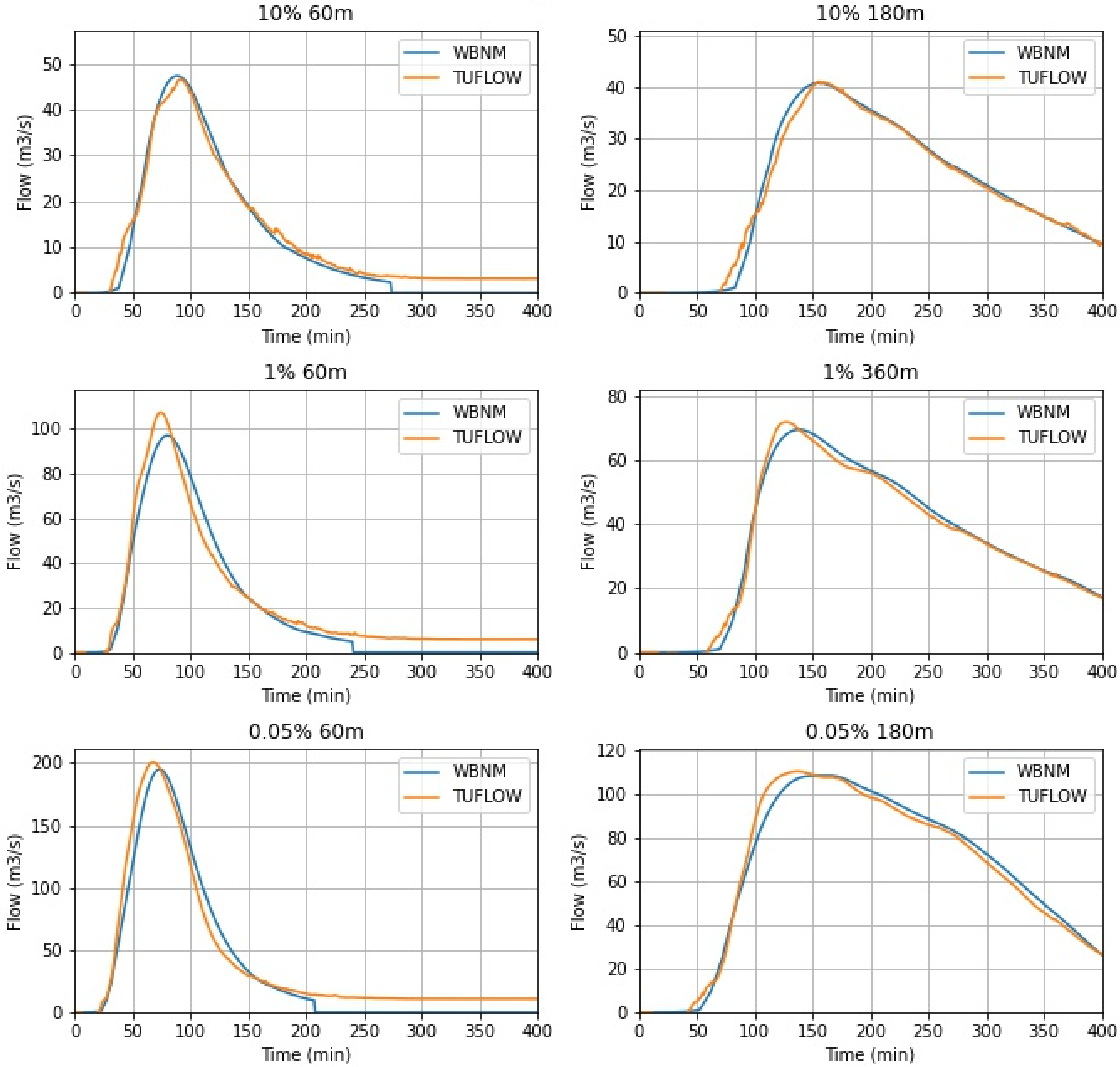

| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 3.77% | 10.0min | 0.88 |
| 10% 180m | 0.4% | 14.0min | 0.93 |
| 1% 60m | 6.23% | 2.0min | 0.95 |
| 1% 360m | 1.81% | 2.0min | 0.96 |
| 0.05% 60m | 3.5% | 2.0min | 0.97 |
| 0.05% 180m | 0.46% | 2.0min | 0.98 |

# CTC001_00697




| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 1.16% | 6.0min | 0.95 |
| 10% 180m | 0.09% | 6.0min | 0.97 |
| 1% 60m | 8.08% | 1.0min | 0.97 |
| 1% 360m | 3.82% | 4.0min | 0.98 |
| 0.05% 60m | 0.7% | 0.0min | 0.98 |
| 0.05% 180m | 0.72% | 6.0min | 0.99 |

# CTC001_00116




| | Peak diff (%) | Peak timing diff (min) | NSE |
|---|---|---|---|
| 10% 60m | 1.52% | 3.0min | 0.98 |
| 10% 180m | 0.62% | 0.0min | 0.99 |
| 1% 60m | 10.74% | 5.0min | 0.96 |
| 1% 360m | 3.43% | 11.0min | 0.99 |
| 0.05% 60m | 3.08% | 6.0min | 0.96 |
| 0.05% 180m | 1.81% | 26.0min | 0.99 |

# APPENDIX D
# POI ARF CLASSIFICATION

| POI ID | Area $km^2$ | ARF class |
|---|---|---|
| CTC004_00461 | 0.5 | A |
| CTC001_06344 | 0.5 | A |
| CTC001_05331 | 0.8 | A |
| KED019_01030 | 0.9 | A |
| CTC001_04377 | 1.2 | A |
| CTC001_03980 | 2.1 | B |
| CTC001_03080 | 2.6 | B |
| CTC001_01137 | 4.1 | B |
| CTC001_00697 | 4.8 | B |
| KED001_07159 | 4.9 | B |
| CTC001_00116 | 5.2 | C |
| KED001_05445 | 6.7 | C |
| KED004_00000 | 16.1 | D |
| KED001_04318 | 23.0 | D |
| KED001_01923 | 31.1 | D |
| KED001_00979 | 32.1 | D |
| KED099_00786 | 34.6 | D |

# APPENDIX E
# HEH METHODOLOGY MEMO

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

ABN: 54 010 830 421

# Technical Note

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

## Overview

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

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

## Aim

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

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

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

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

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

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

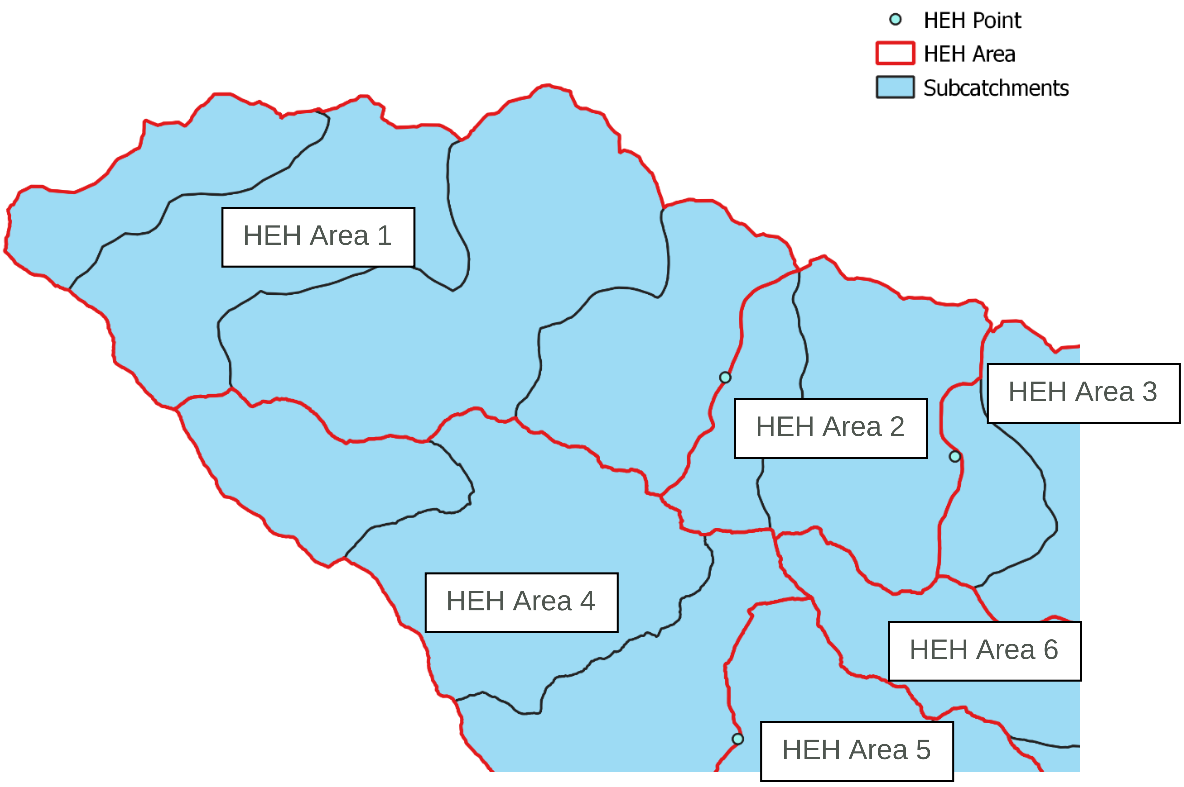



Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

The remainder of this Technical Note includes the following sections:

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

## Definitions

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

## Specifications

### Model simulations

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

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

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

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

### Identification of artificial storages at HEH point

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

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

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

[3] ARR1987 splits temporal patterns into two ARI buckets (above and below the 30-year ARI)
[4] BMT notes that these values are understood to be based on a lag parameter of 1.7, the average value found in the WBNM guidelines. Values may need to be scaled up or down with the selected lag parameter best suited to the catchment (established during the calibration process).

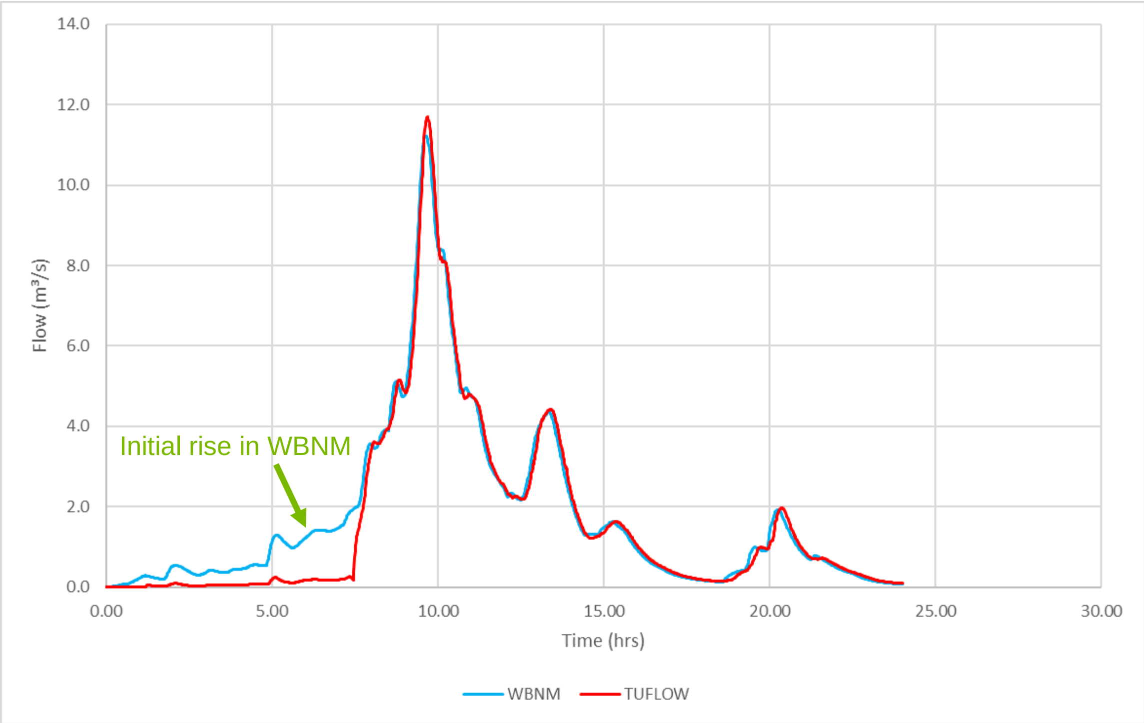



Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

## Criteria for 'matching' the hydrographs at each HEH point

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

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

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

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

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

## Detailed Steps

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

### Flowchart

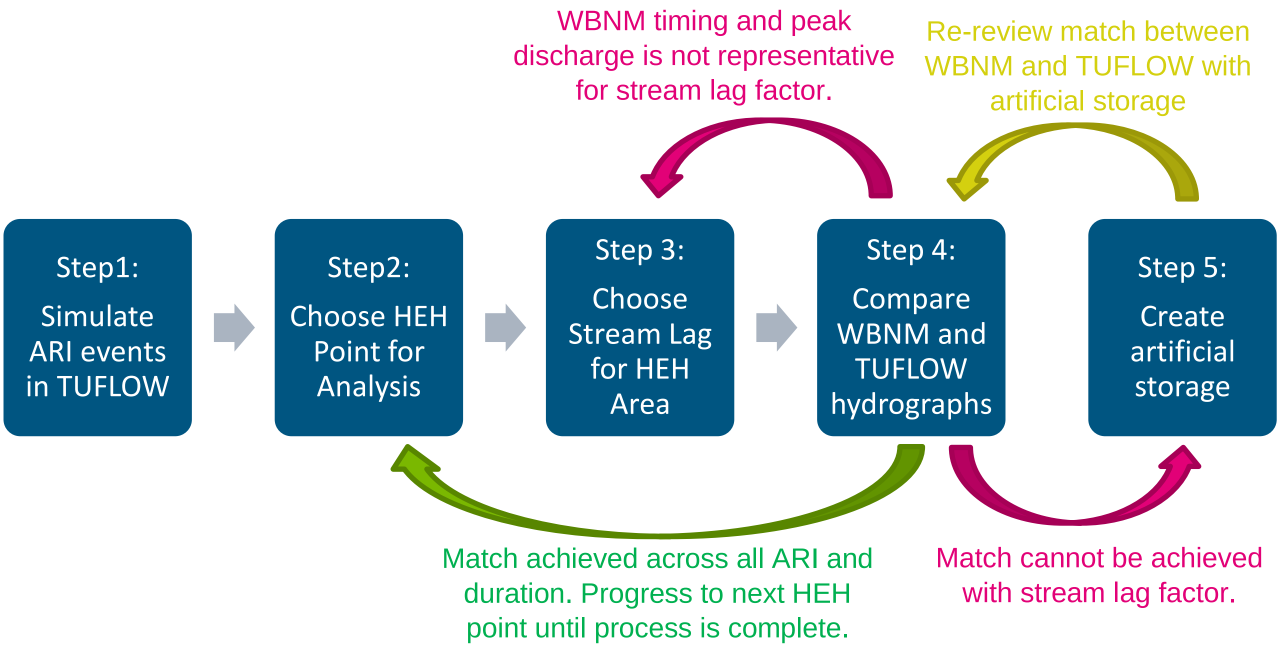



Figure 1.3 Flow chart for the HEH model methodology

### Step 1: Simulate ARI events in TUFLOW

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

### Step 2: Choose a HEH point for Analysis

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

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

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

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

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

### Step 4: Compare against TUFLOW hydrograph

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

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

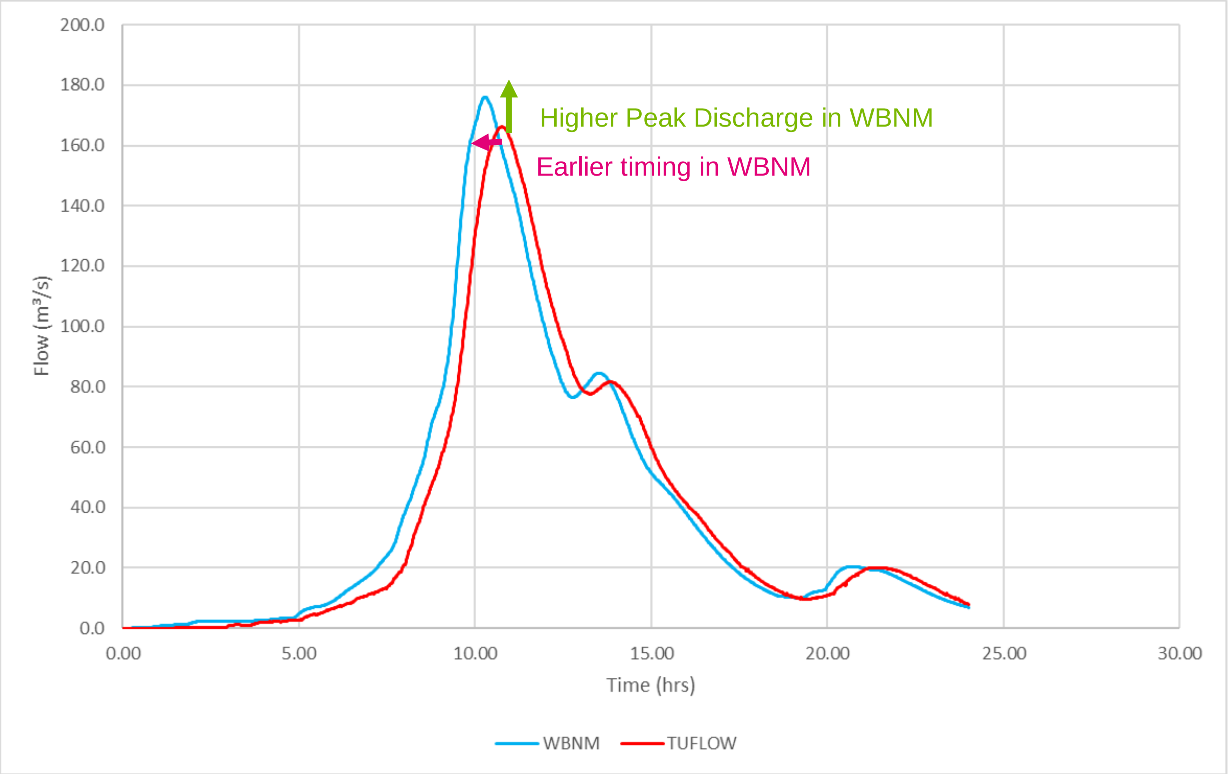



Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

### Step 5: Create an artificial storage

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

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

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

#### Develop the Storage-Outflow table

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

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

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

**Step 5.1 Calculate the storage at each timestep**

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

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

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

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

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

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

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

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

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

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

Figure 1.5 Calculation of Storage

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

**Step 5.2 Construction of the ideal storage-outflow curve**

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

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

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

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

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

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

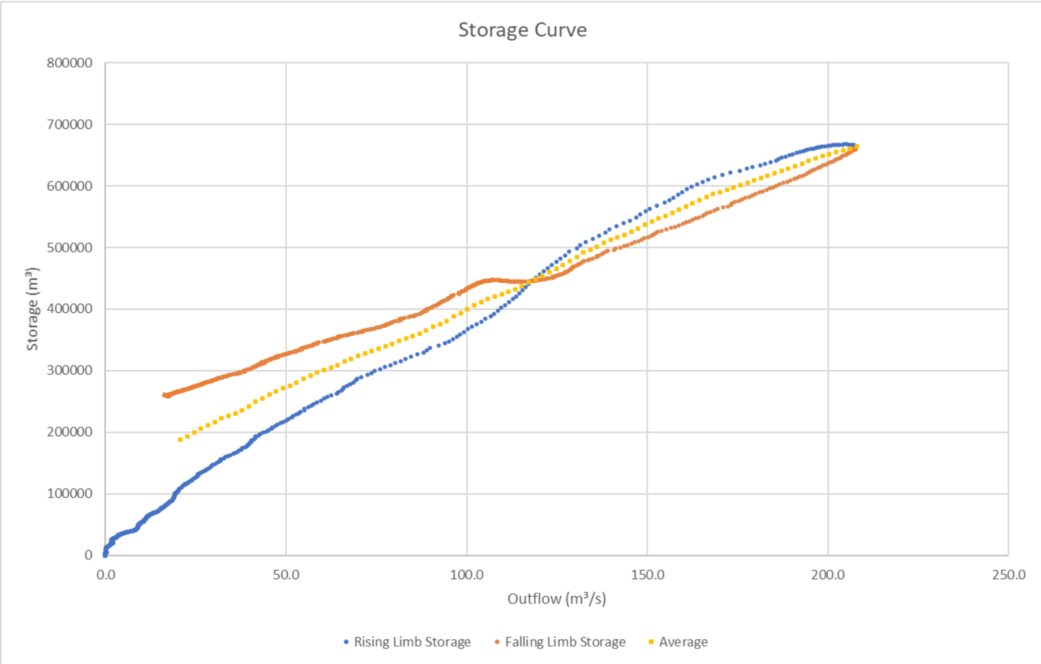



Figure 1.6 Ideal Storage-Outflow Curve

Light green dots result in
a curve which is not ideal

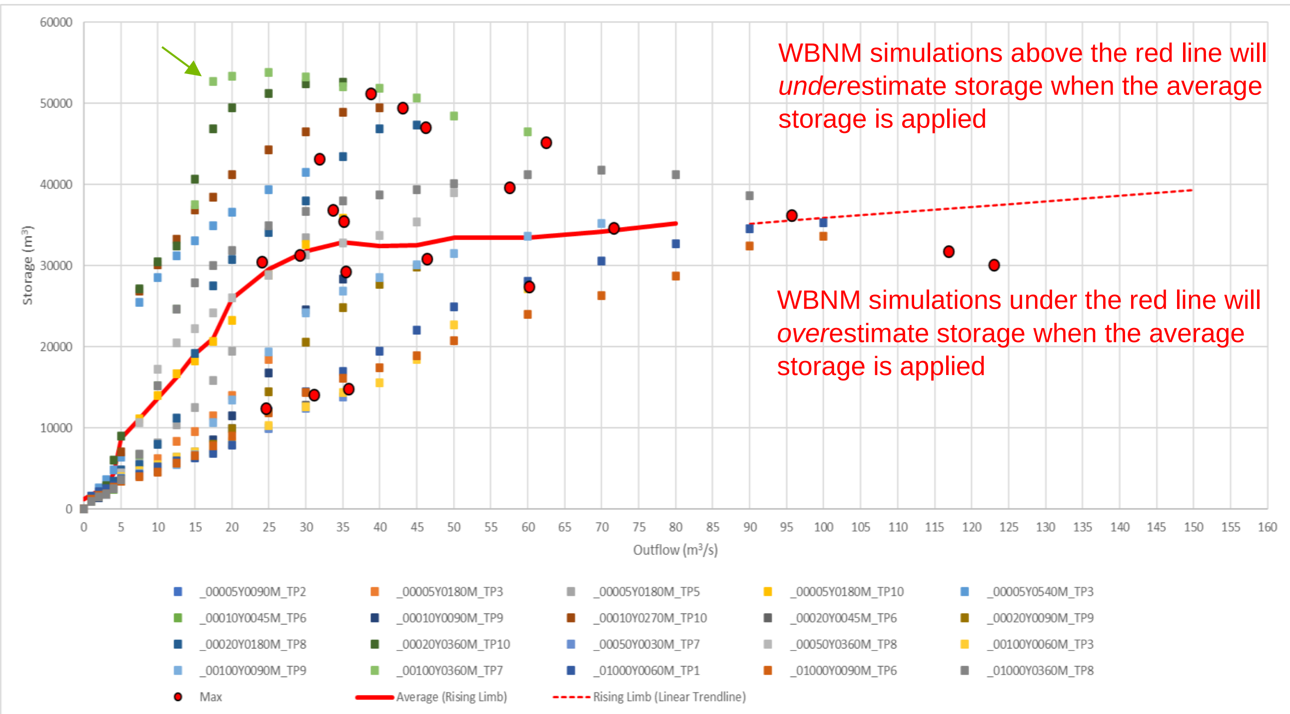



Figure 1.7 Example of an averaged S-Q curve (storages extracted from the rising limb of each duration and ARI)

## Develop the HSQ rating curve (optional)

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

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

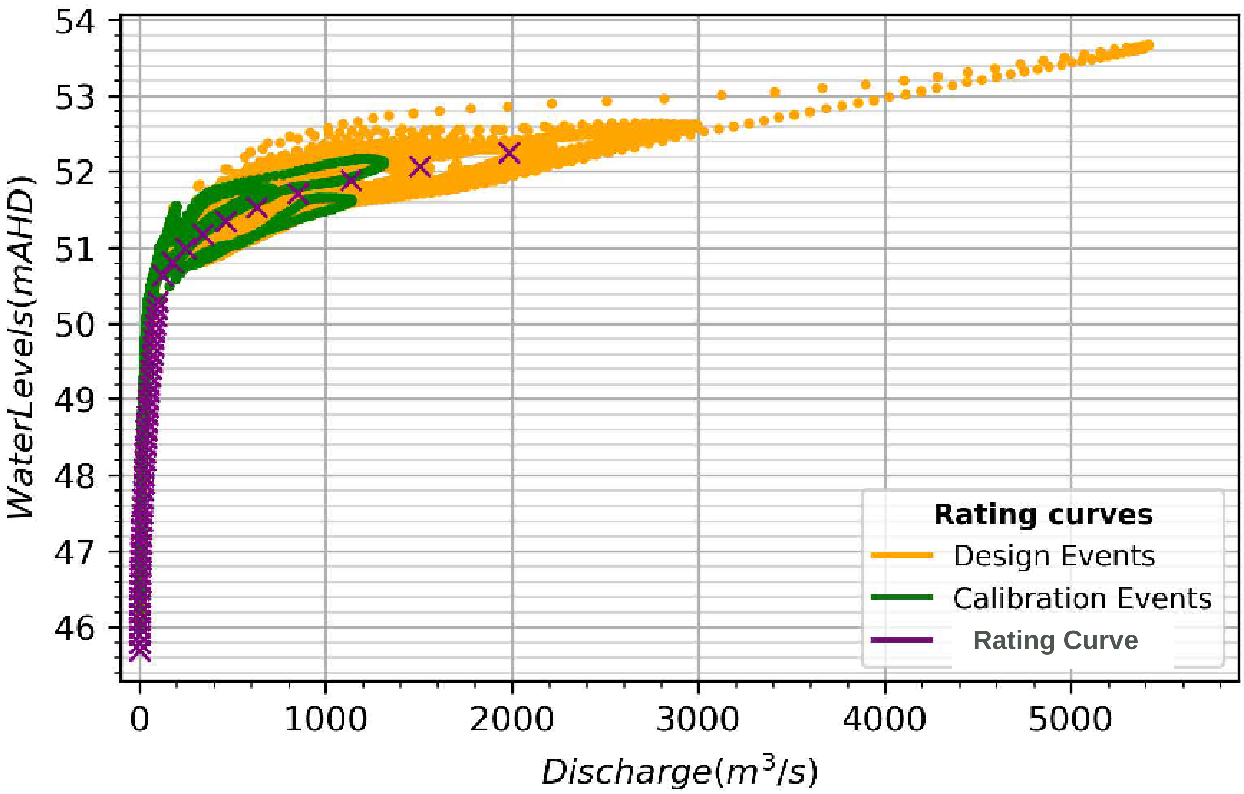



Figure 1.8 Rating curve with hysteresis

## Implementation into WBNM

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

Table 1.2 Outlet Structures Block Variables

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