Regional Flood Database:

2022 Major Flood Model Update
Sideling Creek (SID) Catchment

Moreton Bay Regional Council

Regional Flood Database: 2022 Major Model Update - Sideling Creek Catchment (SID) - Final Report

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Synopsis	This report summarises the tasks of Stage 4 and Stage 5 of the RFD 2022 Update in the Sideling Creek catchment including model updates, model calibration, the development of HEH models and the design event modelling.

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Executive Summary

Moreton Bay Regional Council (Council) has developed the Regional Flood Database (RFD) in 2009, which includes a suit of hydrologic and hydraulic models across the Local Government Area (LGA) and has since been updated when major changes occur in the catchment and if updated data, guidelines and/or updates to the modelling techniques become available.

In 2019, Council initiated a major update to the RFD models implementing the latest Australian Rainfall and Runoff (ARR)[1] guideline, updated and additional structure and landuse data and recent development in the TUFLOW modelling software. This major RFD update is undertaken in 5 stages.

Stage 1 to 3 were undertaken in 2019 to 2021 to update landuse data and test the application of the latest ARR guideline and updates to the TUFLOW software (Heavily Parallelised Compute (HPC), Sub-grid sampling (SGS), quadtree mesh) to inform the model configuration for the RFD.

Stages 4 and 5 are part of this project and include:

Stage 4:

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

Stage 5:

- Design event modelling for 2020 and future conditions
- Design event flood surface creation for 2020 and future conditions

This report summarises tasks and outcomes for Stage 4 & 5 in the Sideling Creek catchment and includes further detail through the Technical Notes provided in the Annexes. This Stage 4 & 5 report includes:

- Section 3: the WBNM and TUFLOW model updates undertaken.
- Section 4: the Stage 4 model techniques and methodologies for model calibration, validation to historic events and the development of HEH models.
- Section 5: Model results and outcomes for model calibration, validation to historic events and the development of HEH models.
- Annex A Technical Note: Model calibration SID Catchment
- Annex B Technical Note: HEH modelling methodology
- Annex C Technical Note: HEH modelling results and summary
- Annex D Technical Note: HEH result plots and summary tables
- Annex E Technical Note: Sideling Creek Design Event Hydrologic Modelling

The updated 2022 RFD models will be used by Council to provide latest flood information to the community and developers to minimise the risk of flooding and improve flood awareness and operations during flood events. The SID WBNM and TUFLOW models developed in this study are considered fit for purpose for floodplain planning and flood forecasting.

[1] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019.

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1 Introduction

Moreton Bay Regional Council 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 Moreton Bay Regional Council (MBRC) area. The RFD model library includes coupled hydrologic and hydraulic models, one for each of the 'minor basins' within the Moreton Bay Regional Council (Council) area. These models were developed in 2009 and have since been refined and updated regularly to include more recent data (i.e. structure, topography, development) and implement advances in latest flood modelling techniques available using WBNM and TUFLOW,

Another major change in this 2022 RFD Major Update Project is the national guideline for flood estimation, Australian Rainfall and Runoff (ARR)[2]. This guideline underwent a major revision in 2016 and then a minor update in 2019.

In preparing for this model update, Council has invested in foundational projects (Stages 1 to 3) to test proposed methods, prepare model data, and to test potential modelling approaches. As part of Stage 4 and Stage 5 of the RFD Major Update Project, BMT has been commissioned by Council to update the following three (3) catchments: Sideling Creek (SID), Upper Pine River and Lower Pine River in combination with Hays Inlet.

The primary objectives of the Stage 4 study are:

- Update of the WBNM hydrologic models and TUFLOW hydraulic models according to the outcomes of the Stage 1 project and utilising the findings of the Stage 3 project
- Model calibration and validation
- Develop 'hydraulically equivalent hydrologic' (HEH) model.

The primary objectives of the Stage 5 study are:

- Design event modelling for 2020 and future conditions
- Design event flood surface creation for 2020 and future conditions

This report details the project methodology, results and outcomes associated with the SID minor basin for Stage 4 of the RFD Major Update 2022.

In the remainder of this report the RFD Major Update Project is referred to as '2022 RFD model update'.

[2] Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors) Australian Rainfall and Runoff: A Guide to Flood Estimation, © Commonwealth of Australia (Geoscience Australia), 2019.

2 Background

The Sideling Creek (SID) hydrologic and hydraulic models were initially developed as part of the Stage 2, Regional Flood Database[3]. In 2014, the SID catchment was upgraded to incorporate the most recent data, including the latest LiDAR elevation data and additional structure details, as improved modelling platform and techniques as part of the RFD 2014 Model Maintenance project[4].

The 2022 RFD major update is being delivered in five stages, with Stage 1, 2 and 3 having been completed:

- **Stage 1 – Pilot Study**[5] – investigated the required/ recommended modelling methodology changes for the RFD utilising ARR 2019 guidelines.
- **Stage 2 – Hydrography Land use and Hydrology**[6] – entailed update of Council's land use roughness layers, catchment delineation and hydrology models.
- **Stage 3 – Hydraulic model configuration investigation**[7] – was an internal investigation conducted by Council staff reviewing recently released software computation methods and capabilities to identify potential application to RFD hydraulic model setup.

[3] WorleyParsons (2012) Regional Flood Database, Hydrologic and Hydraulic modelling Report: Sideling Creek (SID)
[4] BMT (2015) Regional Flood Database 2014 Model Maintenance Report, Sideling Creek (SID)
[5] ARUP (2021) Regional Flood Database ARR 2019 Pilot Study
[6] AECOM (2019) Regional Flood Database, Hydrography Landuse and Hydrology Update 2019
[7] MBRC (2021) RFD Update Stage 3: Analysis Summary

3 2022 Major Model Update Details

3.1 Key Methodology Changes related to ARR19

The methodology update behind the RFD is primarily based on the national guideline for flood estimation, Australian Rainfall and Runoff (ARR). The update of ARR encourages a much broader range of hydrological variability when producing design estimates, such as a range of temporal patterns and varying areal reduction factors (ARF) across the catchment.

Based on Stage 1, it is recommended that hydrological variability is assessed in Hydraulic Equivalent Hydrologic (HEH) models using WBNM with flood levels being produced by a subset of the outputs using a TUFLOW model. The ARR guideline suggest this hydrological variability is best simulated using an ensemble framework.

3.2 IFD Update

The IFD data in this 2022 RFD model update are significantly different to the IFD data used in the previous RFD model updates which was based on ARR 1987.

Moreton Bay Regional Council, in conjunction with Ipswich City Council, Lockyer Valley Regional Council and Moreton Bay Regional Council, have conducted a study[8] to derive new local design rainfall estimates for the council areas, termed the LIMB 2020 IFDs. The LIMB specific data information is available online on https://data.arr-software.org/limb_specific.

3.3 WBNM Model Update

Council has provided an updated WBNM model and associated sub-catchments for the SID catchment, developed as part of Stage 2 of the RFD major update. The updated WBNM model has incorporated refinements and revised parameters to the fraction impervious values, hydraulic roughness, catchment delineation and stream lag factors. In general, the updated WBNM model resulted in changes to peak flow and volume in urban areas (particularly dense urban areas) and minor changes in undeveloped areas. Refer to the Stage 2 Report for further details.

3.4 TUFLOW Model Update

The changes applied to the TUFLOW models are summarised in Table 3.1. Figure 3.1 shows the TUFLOW model extent and the flood extent for the February 2022 flood event to represent the model extent. The TUFLOW model extent was expanded to ensure the full flood extent is covered (no glass walling).

[8] WMA Water (2021) Updated Local Design Rainfalls for Brisbane, Ipswich, Lockyer Valley and Moreton Bay Final Report

https://data.arr-software.org/static/pdf/IFD_Report_Final_June2021_compressed.pdf

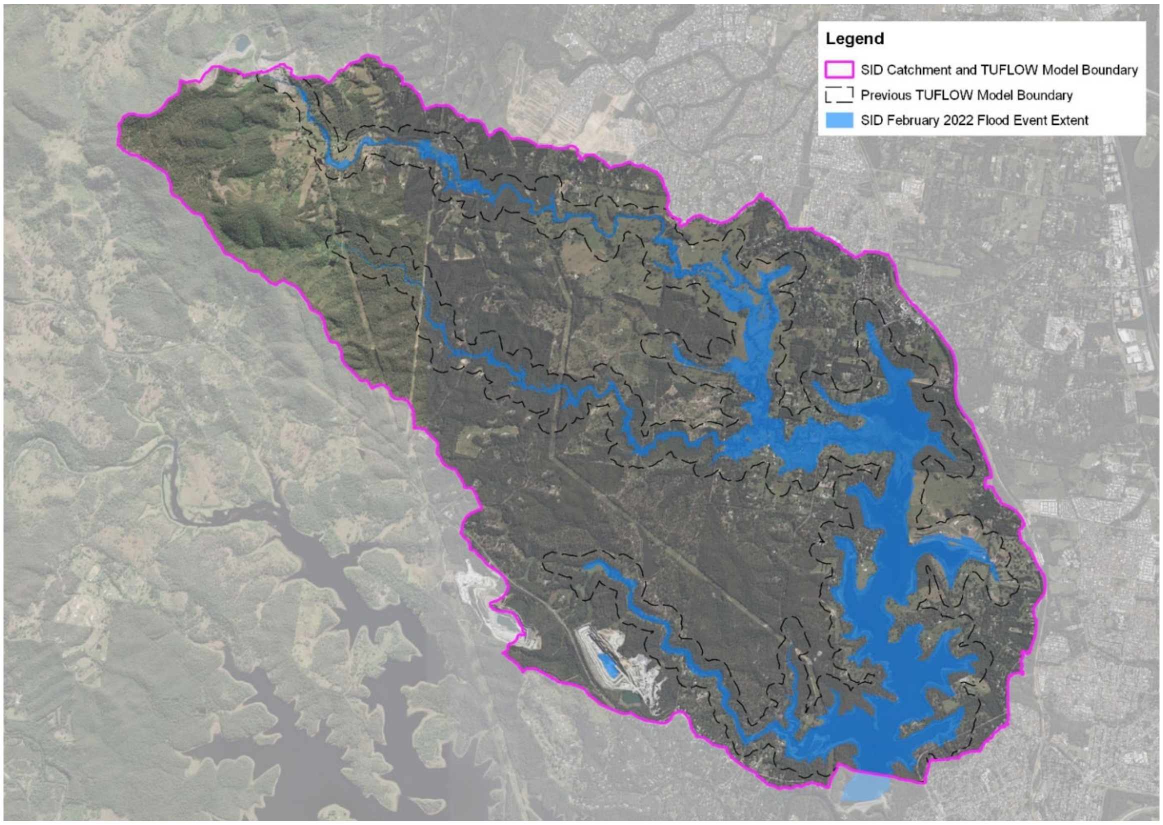


Figure 3.1 TUFLOW Model Extent

Table 3.1 Changes in TUFLOW Model

Change	Details
Model Scheme and Engine	Updated to HPC 2020-10-AC-isP-w64
Hardware	GPU
Viscosity Scheme	Wu viscosity – default for 2020 solver
Cell Size	5m without SGS adopted for final design runs 10m with SGS used for initial calibration runs and 5m without SGS for final calibration runs
Model Extent	2d_code boundary expanded to include entire SID catchment
Terrain	2019 LiDAR Dam DEM Watercourses enforced by updated 2d_zsh streamlines
Structures	Updated 1D stormwater network and culverts based on data provided by Council. Additional road centrelines by using the 2d_zsh new roads layer Additional guard rail and fauna fence information by using the 2d_lfcsh guard rails and fauna fences
Land Use	2019 Pervious-Impervious Raster, developed as part of Stage 2[9] for vegetation density. 2d_mat files to enforce concrete, bitumen, buildings and waterways

[9] AECOM (2020) Regional Flood Database, Hydrography Landuse and Hydrology Update 2019

4 Model Methodology and Simulations

4.1 Calibration and Validation to Historic Flood Events

The SID catchment has been calibrated to the historic event of February 2022 and validated to the January 2011 event. Of these two events, the 2022 event was the larger event, based on peak water level within Lake Kurwongbah and the flood extent. For both events there is limited calibration data available. Table 4.1 provides a summary of the events modelled.

Table 4.1 Modelled Events: SID

Event	Model Start	Model End	Simulation Period (h)
January 2011	9/1/2011 00:00	12/1/2011 01:00	73
February 2022	25/02/2022 02:00	28/2/2022 06:00	76

4.1.2 WBNM

Rainfall Data
Event rainfall data has been provided by Council from available stations. Additionally, BMT have sourced external daily rainfall recordings from Bureau of Meteorology. Different rainfall temporal pattens and rainfall depths were applied at the various gauge locations, refer to the following sections for each historic event.

February 2022 Event

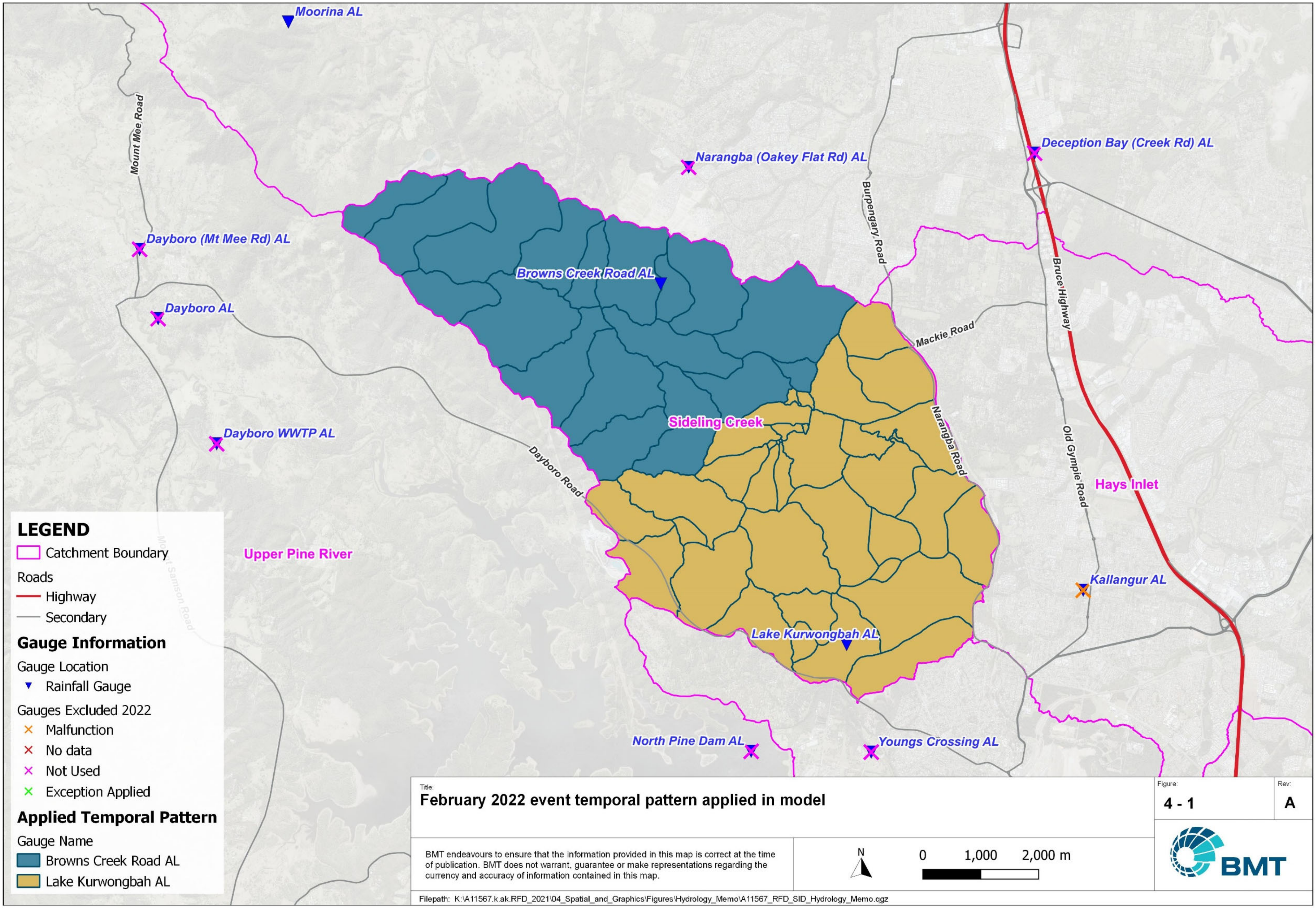
Rainfall loss values of 60mm initial loss and 1.0mm/h continuing loss were adopted for the 2022 event calibration. Table 4.2 lists the gauges used in the event. Figure 4.1 shows the temporal pattern applied for each sub-catchment and Figure 4.2 shows the distribution of rainfall totals applied in the WBNM model. Refer to Annex A for more information on temporal patterns and rainfall.

Key points regarding applications of rainfall gauges are:

- Dayboro (Mt Mee) AL rainfall total was given preference over Dayboro AL and Dayboro WWTP AL as the gauge increased rainfall in upstream area of Mosquito Creek and Brown Creek providing a better calibration.
- Kallangur AL rainfall total was included, noting that the gauge malfunctioned towards the end of the event.
- The gauges within the catchment were used for temporal patterns.
- No available daily rainfall gauges were required.
- The 1.0mm/h continuing loss was selected based on the hydraulic model results.

Table 4.2 Rain Gauges Applied – February 2022

Gauge Name	Gauge ID	Temporal Pattern	Depth	Total Recorded Rainfall (mm)
Browns Creek Road AL	540411	✓	✓	868.0
Lake Kurwongbah AL	540204	✓	✓	1012.0
Moorina AL	540358		✓	834.0



Title:

February 2022 event temporal pattern applied in model

Figure: 4 - 1

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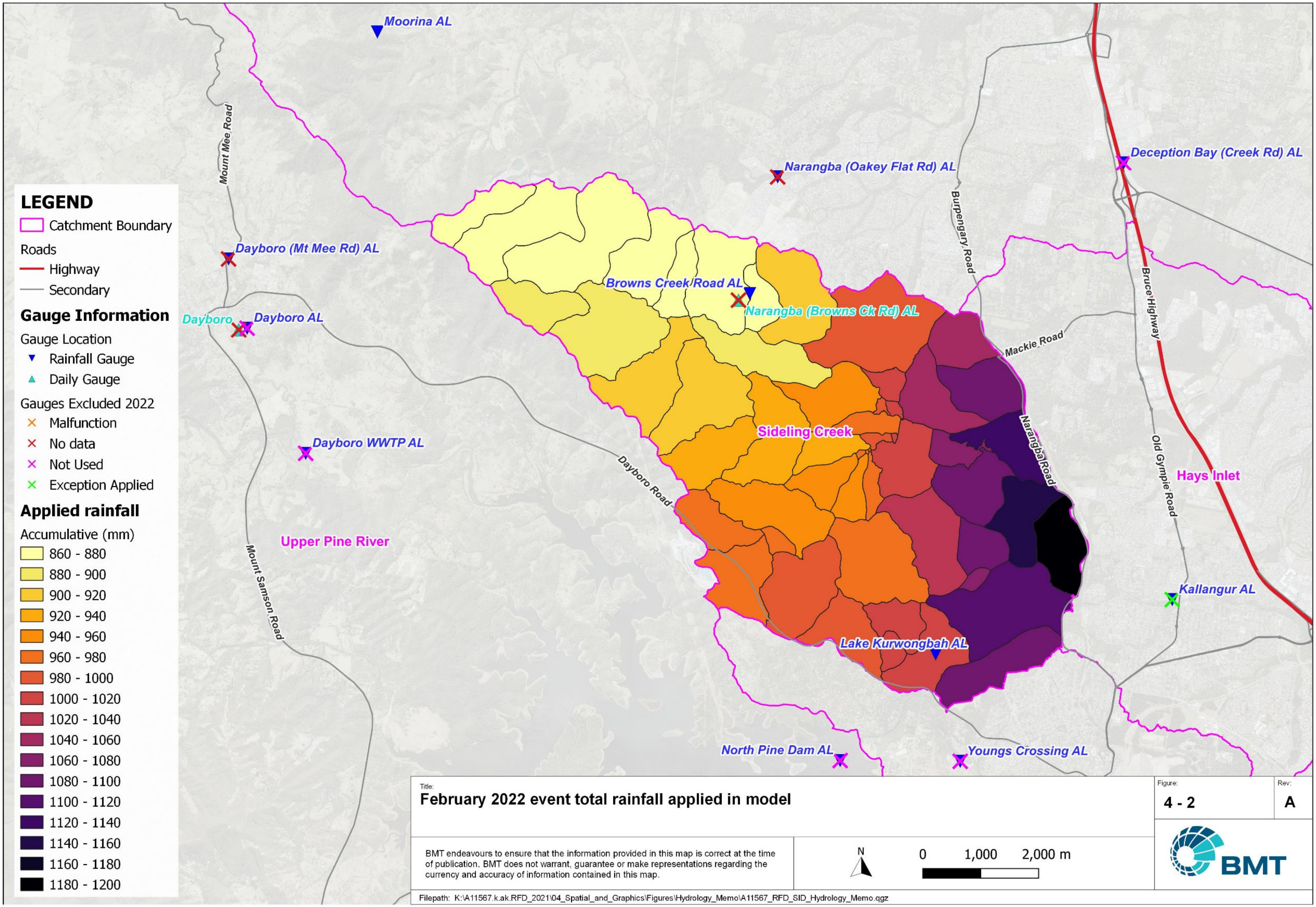

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February 2022 event total rainfall applied in model

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January 2011 Event

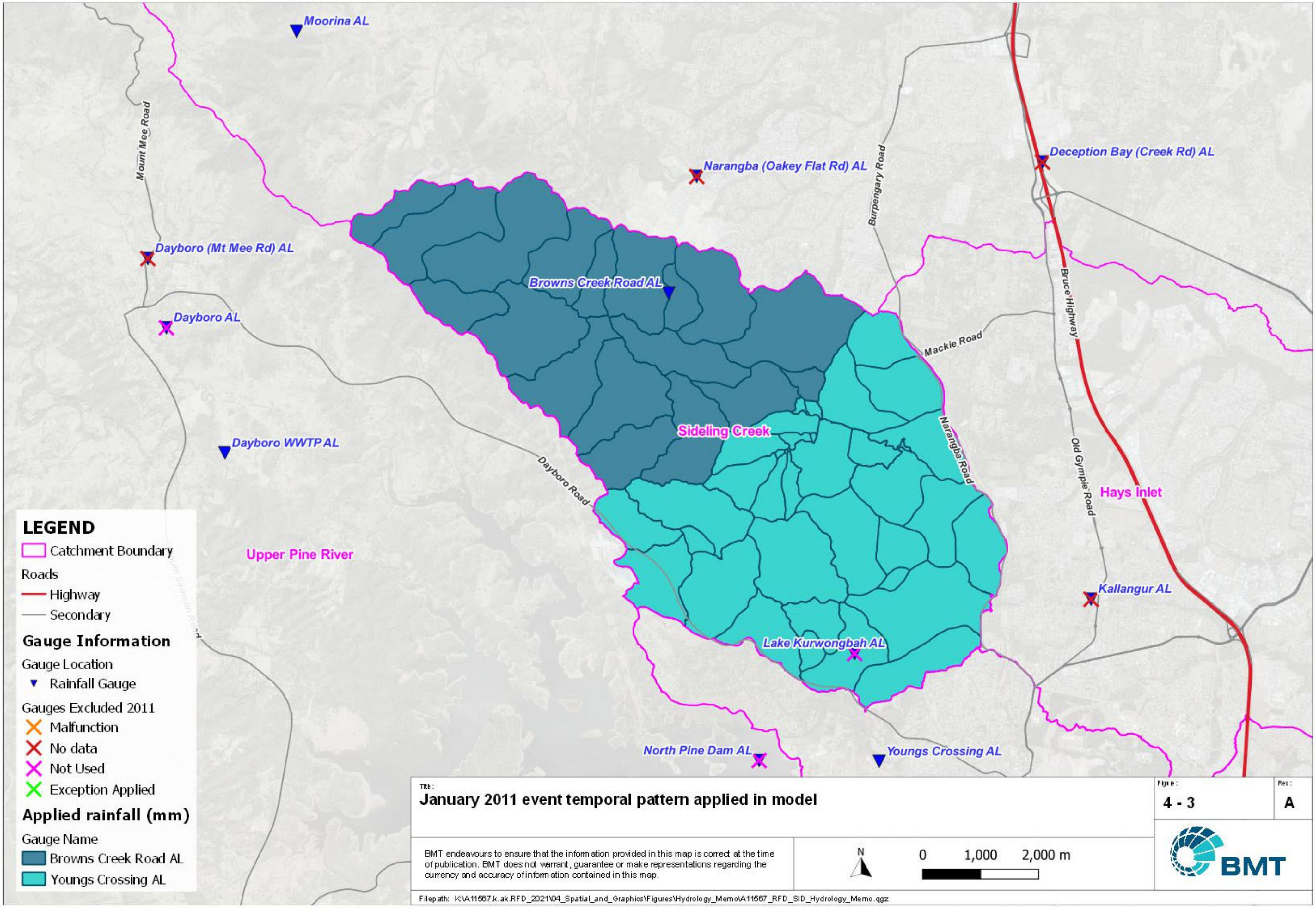
Rainfall loss values of 10mm initial loss and 1.0 mm/h continuing loss were adopted for the 2011 event validation. Table 4.3 lists the gauges used in the event. Figure 4.3 the temporal pattern applied for each sub-catchment and Figure 4.4 shows the distribution of rainfall totals applied in the WBNM model.

Key points regarding application of rainfall gauges:

- Lake Kurwongbah AL appears to have failed between approximately 3am 10 January until 12pm 10 January 2011, therefore Youngs Crossing AL was preferred.
- Given the low coverage of nearby rainfall gauges, the external gauge of Burpengary (Dale St) AL and Lipscombe Rd AL were initially considered however these gauges were not beneficial to the outcome.
- No available daily rainfall gauges were required.

Table 4.3 Rain Gauges Applied – January 2011

Gauge Name	Gauge ID	Temporal Pattern	Depth	Total Recorded Rainfall (mm)
Browns Creek Road AL	540411	✓		
Dayboro WWTP AL	540484		✓	536.0
Moorina AL	540358		✓	575.0
Youngs Crossing AL	540412	✓	✓	280.0



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January 2011 event temporal pattern applied in model

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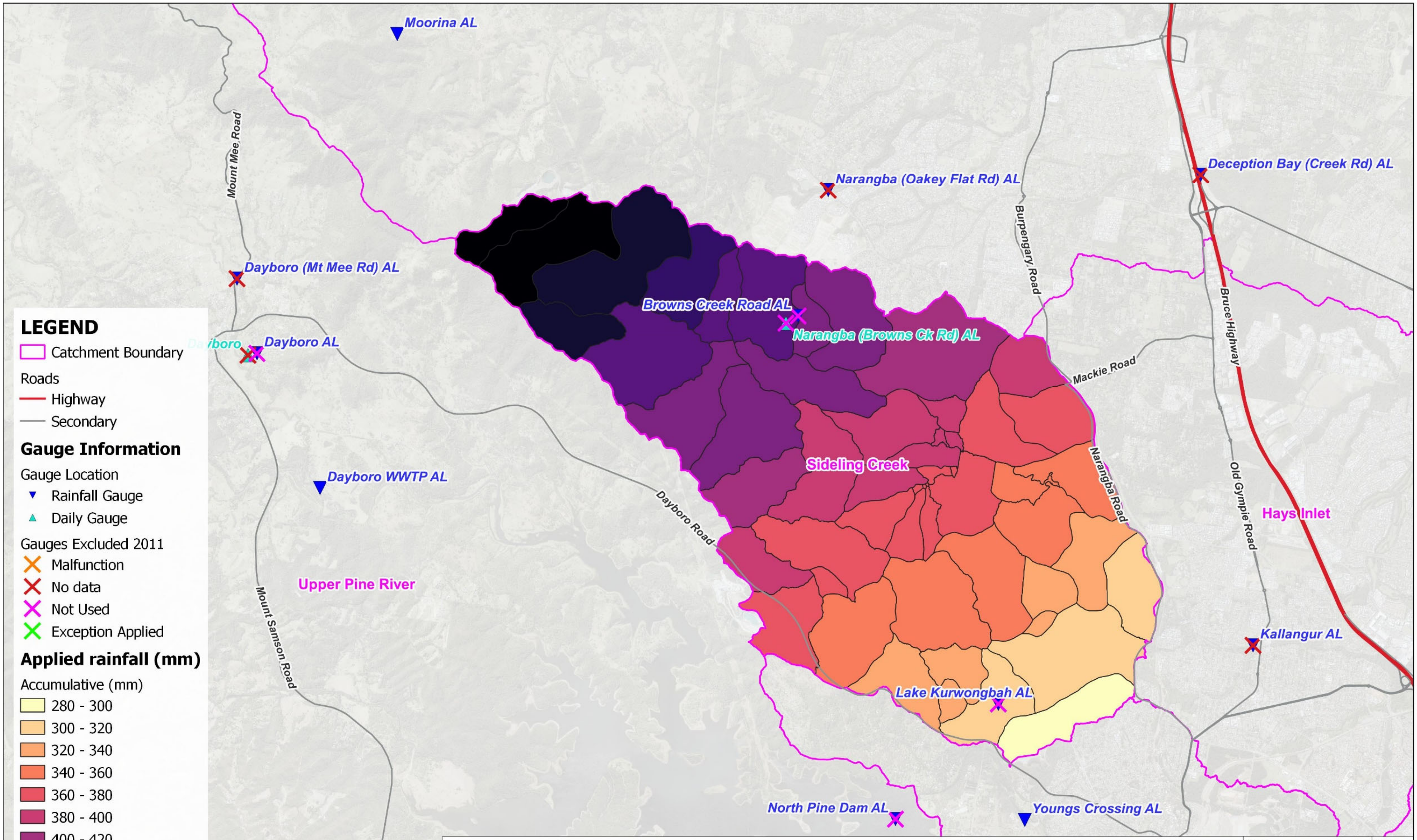

Title:
January 2011 event total rainfall applied in model

Figure: 4 - 4

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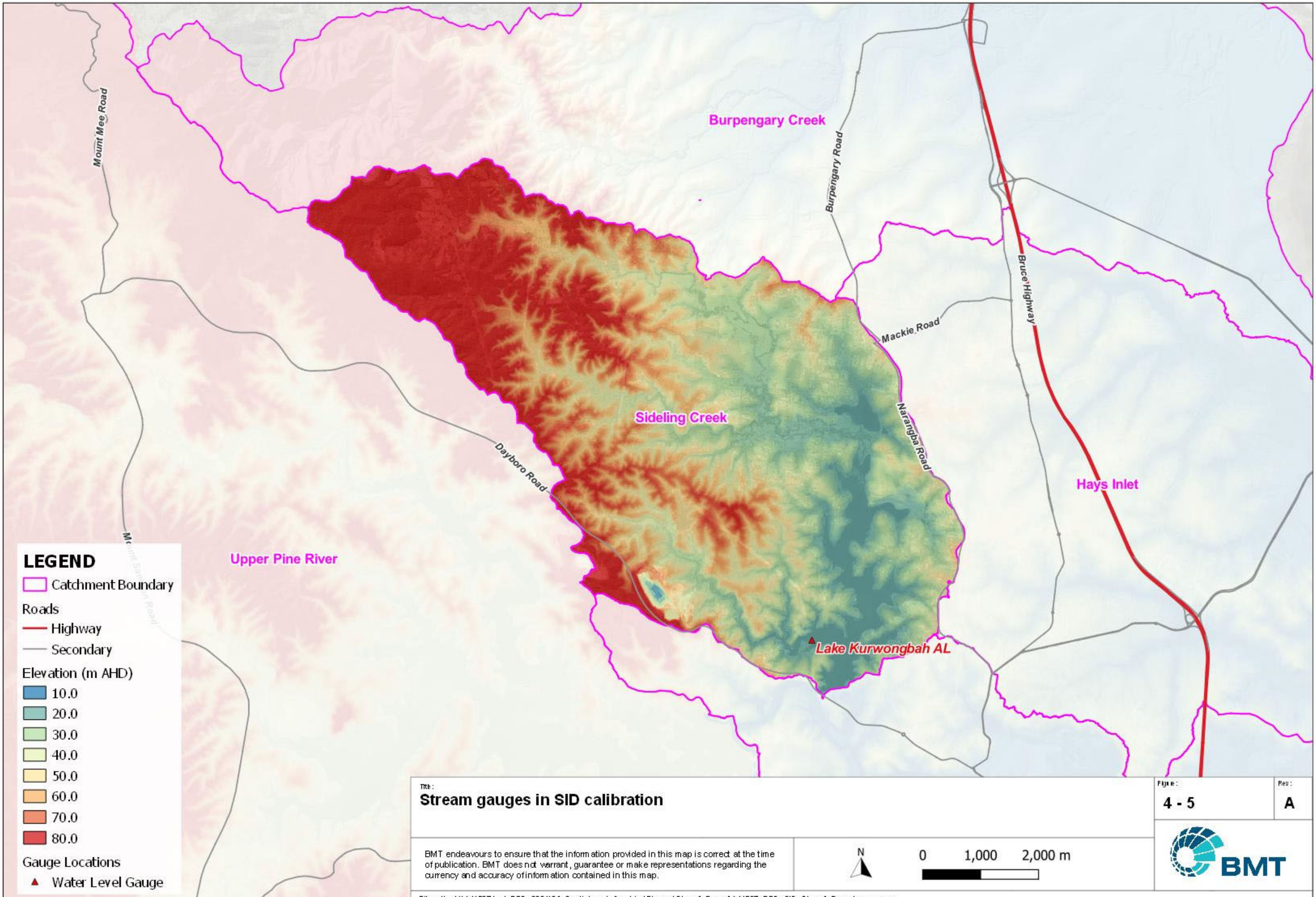
Stream Gauges

Stream gauge information recording event water levels in the SID catchment was only available for Lake Kurwongbah for the 2022 event. The recorded water level in Lake Kurwongbah has been used to compare against modelled results for the 2022 event by assessing the match to flood peak, timing, volume and hydrograph shape. Table 4.4 lists the available data.

Table 4.4 Available Stream Gauges

Gauge Name	Gauge ID	Watercourse	2011	2022
Lake Kurwongbah AL	540204	Sideling Creek		✓

For both the January 2011 and the February 2022 event, the outflow from the Lake Kurwongbah Dam was provided by Council. As there is no available recorded water level in the lake for the 2011 event, the modelled dam level has been compared to the recorded dam releases for that event.



Title:

Stream gauges in SID calibration

Figure: 4 - 5

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Surveyed Flood Marks

For the SID catchment, 21 flood marks were surveyed following the January 2011 event. These are all rated as having a 'medium' indicative quality. No flood marks were recorded following the February 2022 event in the SID catchment.

4.1.3 TUFLOW

Model Changes

The simulations for the 2011 and 2022 events were both consistent with the updated model, that is there were no significant changes applied to the model for those two events.

4.2 Hydraulic Equivalent Hydrologic (HEH) Model Development

Hydraulic Equivalent Hydrologic (HEH) models were developed as part of the 2022 model update. The development of HEH models was initially proposed as part of Stage 1 pilot study. The aim of the HEH modelling 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 catchment.

The match of hydrographs has been considered in respect to peak discharge (peak ratio), 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 applying the latest Australian Rainfall and Runoff (ARR2019) guideline. This selection process will limit the need to simulate all temporal patterns and durations for each annual exceedance probability (AEP) design event in the hydraulic model leaving just the 'AEP neutral' simulations. This process therefore provides a more efficient procedure in temporal pattern and duration selection whilst retaining a desired level of accuracy.

Methodology

A flow chart of the process for implementing the HEH model methodology is provided in Figure 4.6.

For comprehensive details of HEH model methodology, refer to Annex B, which includes a Technical Note on the HEH Modelling Methodology. A flow chart of the process for implementing the HEH model methodology is provided in Figure 1.3, Annex B.

Specific details regarding the steps involved in the implementation of the HEH methodology within the SID catchment are summarised in Table 4.5.

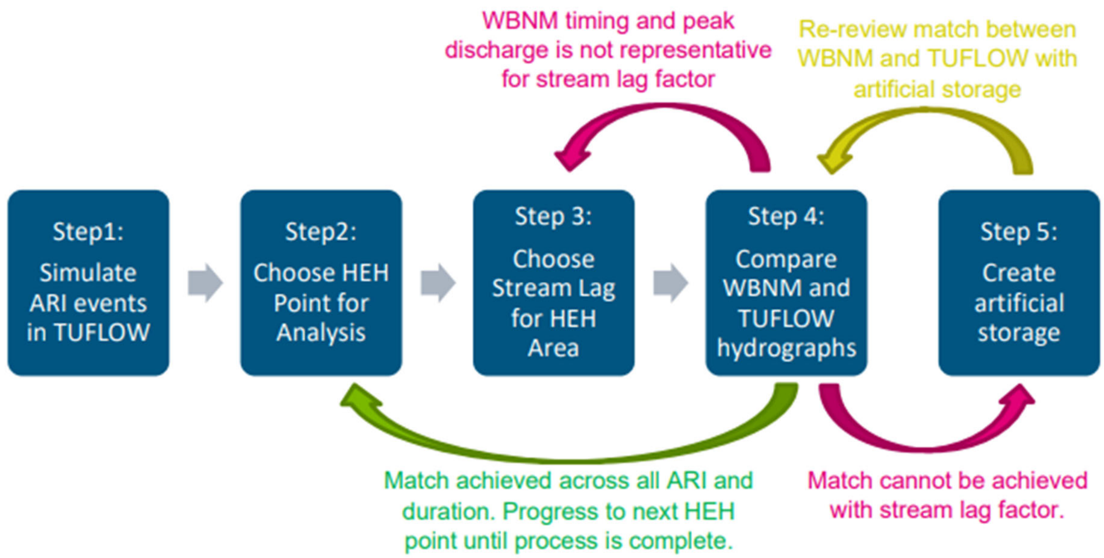


Figure 4.6 Flow chart for the HEH model methodology

Table 4.5 Further Details when Implementing HEH Model Development

Step	Comment
1	The following ARI events and durations were simulated through the TUFLOW model[10]: • ARI events– 5-year, 20-year, 100-year, 2000-year • Durations – 60-minute, 120-minute, 360-minute
2	HEH points were ordered so that multiple HEH points could be reviewed simultaneously.
3	Multiple models were setup to run consecutively with different stream lag factors. The models started with a stream lag factor of 0.2 and incrementally increased by 0.05 to a final stream lag factor of 1.25 (22 simulations in total).
4	The following was undertaken for comparison: • The WBNM outputs were interpolated to match the TUFLOW output interval of 5-minutes. • WBNM total flows at confluences were combined. • At culvert locations, where TUFLOW contains both flow in 1D and 2D domains, the 1D and 2D flows were combined. • A scoring system was implemented to assess the best outcome from all the stream lag factors simulated in Step 3, or after the artificial storage implemented in Step 5. This scoring system is described in Annex B
5	The artificial storages were implemented based on the following: • To apply an artificial storage at confluences, an additional dummy sub-catchment with zero area was included where a common sub-catchment combining the tributary discharge was not included in the supplied sub-catchments. • All simulated stream lag factors in Task 3 were assessed against the ideal WBNM hydrograph for the application of artificial storage in Annex B. 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. The largest stream lag with the most ideal WBNM hydrographs was selected. • The artificial storage was applied using either of the two methods below: - A statistical analysis of the individual event / duration storage calculations. The statistical analysis is then extrapolated out to higher nominal outflow positions, refer Annex B. - All individual storages calculations (all event and duration simulations) have been extrapolated to all nominal outflow positions prior to the statistical analysis being undertaken. The statistical analysis was then calculated on the extrapolated individual storages. An example is also shown in Annex B.

4.3 TUFLOW Hydraulic Model

The output hydrographs derived from the SID WBNM hydrologic model were adopted as inflow hydrographs in the TUFLOW hydraulic model at the corresponding inflow locations.

The downstream boundary of the SID hydraulic model was located at the embankment of Lake Kurwongbah, where the stage-discharge relationship (HQ) derived by SEQWater at the dam spillway was applied as downstream boundary condition. The stage-discharge relationship adopted in the present study is shown in Figure 4.7.

[10] A larger range of ARI and durations were considered during testing of the HEH methodology. A comparison found that there was no significant difference in the establishment of the stream lag factor or the storage calculations with a smaller range of ARI and durations.

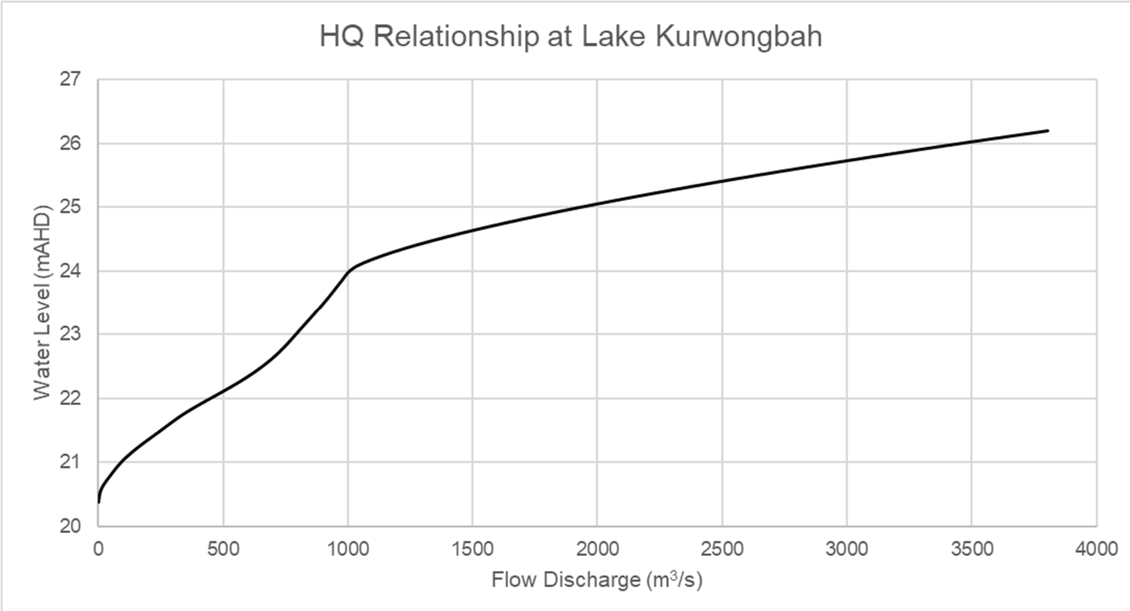


Figure 4.7 SEQWater Stage-Discharge Relationship at Lake Kurwongbah Spillway

Blocked and unblocked scenarios were simulated in the TUFLOW hydraulic model as follows:

- The unblocked scenario included no blockage applied to culverts.
- The blocked scenario was setup as follows:
  - Either a blockage factor or a modified inlet energy loss was applied to culverts in accordance with the methodology adopted by MBRC and outlined in the “Regional Flood Database ARR2019 Pilot Study” report (ARUP, 2021).
  - A blockage factor was applied to Scout Road bridge in accordance with the methodology adopted by MBRC and outlined in the “Regional Flood Database ARR2019 Pilot Study” report (ARUP, 2021).
  - No trunk stormwater pits and pipes were included in the Sideling Creek hydraulic model, therefore, no blockage assessment was carried out for these hydraulic structures.

Key steps of the blockage assessment methodology applied to culverts can be summarised as follows:

- The methodology featured the application of a L10 parameter of 4m in rural catchments and a L10 parameter of 1.5m in urban catchments (i.e., catchments with fraction impervious higher than 15%). Given the rural character of the Sideling Creek catchment, a L10 parameter of 4m was applied to all the culverts in the catchment.
- The blockage assessment was carried out by classifying the AEP events in three main categories: more frequent than 5% AEP, between 5% and 0.5% AEP, rarer than 0.5% AEP.
- The hydraulic behaviour of each culvert was assessed to classify the culverts into inlet and outlet controlled for each AEP category.

- Inlet blockage and barrel blockage factors were calculated for each culvert.
  - If the culvert was inlet controlled, the maximum between the inlet and blockage factors were applied as pBlockage attribute in the 1d_nwk TUFLOW shapefile using the Reduced Area Method approach.
  - If the culvert was outlet controlled, the modified inlet energy loss was calculated for both inlet and barrel blockage. Then, the following assessment was performed:
    - If the modified inlet energy loss from barrel blockage was higher than the loss from inlet blockage, the blockage was modelled as pBlockage attribute in the 1d_nwk TUFLOW shapefile using the Reduced Area Method (RAM) approach.
    - If the modified inlet energy loss from inlet blockage was higher than the loss from barrel blockage, the blockage was modelled as modified EntryC attribute using the Energy Loss Method (ELM) approach. A maximum value of 1 was applied as EntryC attribute, with the excess applied as Form_Loss attribute in the 1d_nwk TUFLOW shapefile.

Table 4.6 provides a summary of the modelled culvert blockage in the Sideling Creek catchment. The blockage assessment highlighted that all the culverts in this catchment were outlet controlled and characterised by similar hydraulic behaviours. Table 4.7 provides a summary of the modelled blockage at Scout Road bridge.

Table 4.6 Modelled Culvert Blockage

AEP Category	pBlockage	Form Loss	Entry Loss
More frequent than 5% AEP	0	0.63	1.0
Between 5 and 0.5% AEP	0	4.83	1.0
Rarer than 0.5% AEP	100	0	0.5

Table 4.7 Modelled Blockage at Scout Road Bridge

AEP Category	L1 Blockage (%)
More frequent than 5% AEP	0
Between 5 and 0.5% AEP	0
Rarer than 0.5% AEP	10

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

The subset of critical storms ran in the hydraulic model was selected based on the HEH model results in order to optimise the simulation runtime while ensuring a high degree of confidence in the TUFLOW model results related to the selection of critical storms. The design storm selection process using the WBNM HEH model is described in detail in the Technical Note: *Sideling Creek Design Event Hydrology Modelling and Results* provided in Annex E.

A summary of the blocked and unblocked, existing and future scenario simulations ran in the hydraulic model for each AEP event is provided in Table 4.8. Separate envelopes of unblocked and blocked scenarios were processed for each AEP event. Envelopes of peak results between blocked and unblocked scenarios were also produced for the existing and future conditions as summarised in Table 4.8.

Table 4.8 Summary of Design Event Critical Storms and Scenarios

AEP	Bucket	Duration and Temporal Pattern (TP)	Existing Unblocked Scenario (E00)	Existing Blocked Scenario (E02)	Envelope Blocked & Unblocked Scenario (E03)	Future Unblocked Scenario (F00)	Future Blocked Scenario (F02)	Future Envelope Blocked & Unblocked Scenario (F03)
0.05%	ARFc	120 (TP1)	✓	✓	✓		✓	
	ARFc	270 (TP7)	✓	✓	✓		✓	
	ARFe	360 (TP10)	✓	✓	✓		✓	
0.1%	ARFc	120 (TP1)	✓	✓	✓		✓	
	ARFc	270 (TP7)	✓	✓	✓		✓	
	ARFe	360 (TP10)	✓	✓	✓		✓	
1%	ARFc	120 (TP8)	✓	✓	✓	✓	✓	✓
	ARFc	270 (TP7)	✓	✓	✓	✓	✓	✓
	ARFe	360 (TP4)	✓	✓	✓	✓	✓	✓
2%	ARFc	120 (TP8)	✓	✓	✓		✓	
	ARFc	270 (TP7)	✓	✓	✓		✓	
	ARFe	360 (TP6)	✓	✓	✓		✓	
5%	ARFc	180 (TP8)	✓	✓	✓		✓	
	ARFe	540 (TP9)	✓	✓	✓		✓	
10%	ARFc	180 (TP4)	✓	✓	✓			
	ARFd	360 (TP7)	✓	✓	✓			
	ARFe	540 (TP10)	✓	✓	✓			
20%	ARFc	180 (TP6)	✓	✓	✓			
	ARFc	270 (TP5)	✓	✓	✓			
	ARFe	720 (TP5)	✓	✓	✓			

5 Model Results and Outcomes

5.1 TUFLOW Hydraulic Model Calibration and/or Validation

Annex A provides details on model results and outcomes for the 2022 calibration event and the 2011 validation event.

Overall, the calibration and validation of the SID catchment to historical events is considered satisfactory although there is limited available calibration data. Modelling of the February 2022 event demonstrates that the model is able to adequately simulate the catchment runoff response into Lake Kurwongbah. There is greater uncertainty with regards to calibration in the catchment area upstream of Lake Kurwongbah as there are no water level gauges and peak flood marks are only available for the January 2011 event for which there is limited rainfall data.

5.2 WBNM Hydraulic Equivalent Hydrologic Model Performance

The final WBNM model stream lag factors, HEH points with applied artificial storage, and final score for each HEH point with the SID catchment are summarised in Table 5.1. The scores in the Table are colour coded according to the degree to which they achieve the desired match, where green represents an excellent score, dark blue a good score, and red a score outside the desired criteria. A map of the stream lag factors, and artificial storage locations is shown in Figure 5.1. For comprehensive results showing the WBNM and TUFLOW hydrographs, refer to Annex C: Sideling Creek HEH Modelling and Results.

The following are findings from reviewing the HEH results for the catchment:

- All HEH points have final scores that are considered either ‘good’ or ‘excellent’, with most of the upstream HEH scores considered ‘excellent’.
- The average of all three criteria at all HEH points is within the desired tolerance (Annex C, Section 3.2), with most points outperforming the desired tolerance.
- In general, the stream lag factors are lower at the top of the catchment and become larger downstream. Only within the waterbody of Lake Kurwongbah does the stream lag factor decrease. It would be expected that the flood water would travel faster than in normal reaches within this waterbody.
- Two storages were applied in Lake Kurwongbah, one at the inlet from Browns Creek and the other at the downstream of the model.

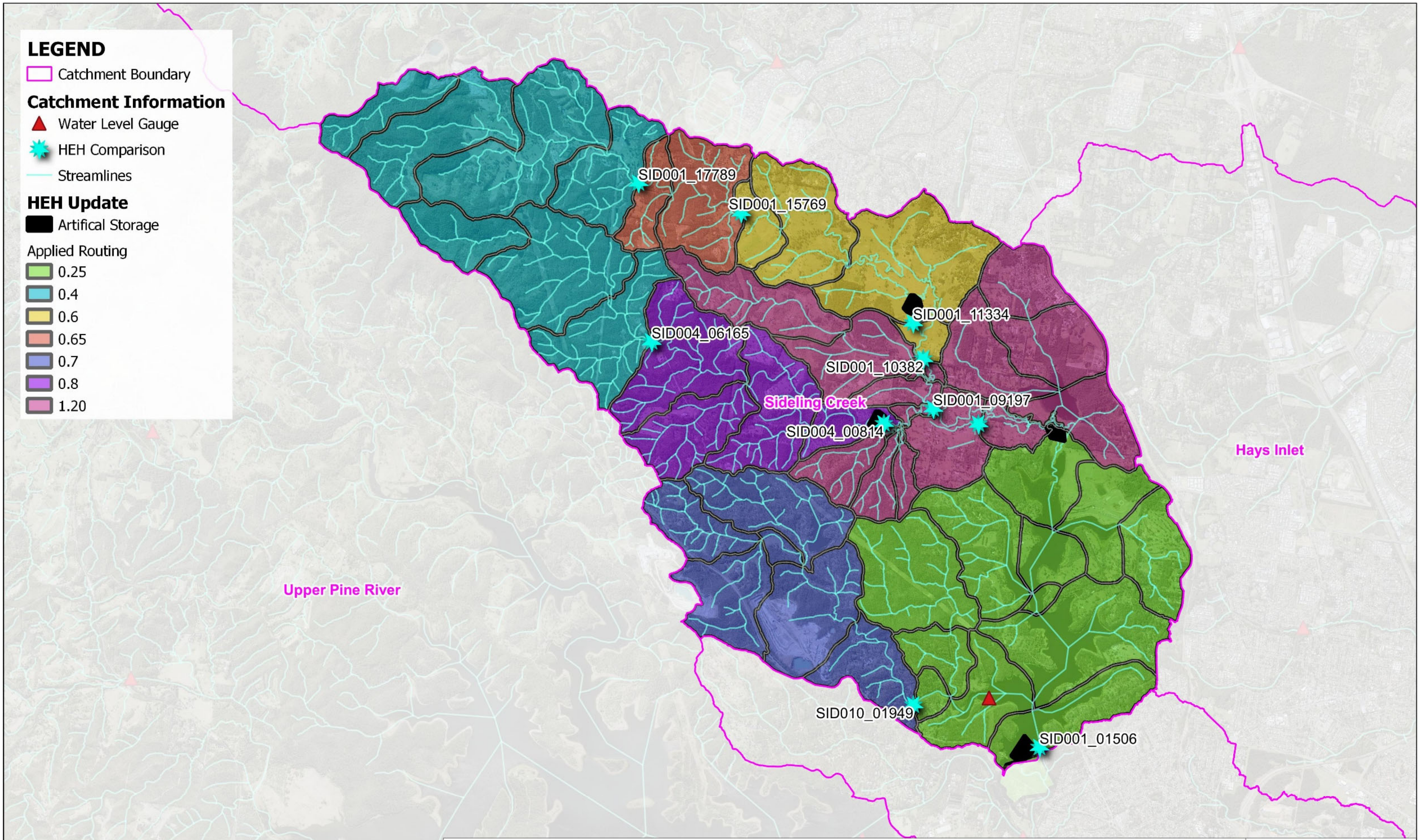
Table 5.1 Adopted Stream Lag Factor, Artificial Storage Information and Final Score

HEH Point Name	Adopted Stream Lag Factor	Artificial Storage Included	Artificial Storage Calculation Method	Final Score (Score without Artificial Storage)	Final Score Rating
SID010_01949^	0.70			19.7	good
SID004_06165	0.40			9.9	excellent
SID004_00814	0.80	✓	Mean (extrapolated)	12.6 (57.7)	excellent
SID001_17789	0.40			11.2	excellent
SID001_15769	0.65			14.7	excellent
SID001_11334	0.60	✓	Mean (extrapolated)	16.1 (117.2)	excellent
SID001_10382	1.00			11.0	excellent
SID001_09197	1.00			11.0	excellent
SID001_08305	1.00			11.6	excellent
SID001_01506	0.25	✓	Mean	26.5 [1,2] (918.6)	good

1 A stream lag factor of 0.25 was used within the dam, whilst a stream lag factor of 1.1 was used to the inlet to Lake Kurwongbah (SID001_06735 and SID003_00000). Higher stream lag factors across the dam were applied with limited success of matching the hydrograph at the model outlet.

2 Two storages were applied, the first at SID001_06735 which had a final score of 11.7 using a 'Mean (extrapolated)' artificial storage calculation.

^ HEH point located near water level gauge



Title:

Applied Routing and Artifical Storage

Figure: **5 - 1**

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5.3 Design Flood Behaviour

2022 Existing Conditions - WBNM HEH and TUFLOW

A comparison of the peak flows derived from the WBNM HEH and the TUFLOW HPC models was undertaken at the points of interest (POI). The critical storm including duration, temporal pattern and the resulting peak discharge for the 1% AEP event at each POI is summarised in Table 5.2.

The comparison between the peak flow discharges estimated with WBNM HEH and TUFLOW models highlighted a very good match between the model results at the selected points of interest, with a maximum difference in peak flows of 4.4% observed at SID004_00814 POI.

Table 5.2 Critical Storm and Peak flows from the SID WBNM and SID TUFLOW models at each Design Event Modelling point for the 1% AEP event

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	WBNM Peak Discharge (m3/s) Existing Conditions 1% AEP Event	TUFLOW Peak Discharge (m3/s) Existing Conditions 1% AEP Event	Difference between WBNM and TUFLOW Peak Discharge (%)
SID004_00814	ARFc	270	7	150.3	143.6	+4.4%
SID010_01949	ARFc	120	8	108.0	108.7	-0.6%
SID001_10382	ARFc	270	7	205.6	202.7	+1.4%
SID001_08305	ARFd	270	7	396.6	413.5	-4.3%
SID001_01506	ARFe	360	4	458.7	446.3	+2.7%

2022 vs 2014 Existing Conditions

Differences in flood levels and extent were assessed when comparing the 2022 1% AEP peak flood levels for the existing conditions and 2014 RFD peak flood level grids existing conditions for the unblocked scenario. These differences are mainly related to the application of ARR 2019 guidelines, which are characterised by updated IFD curves and by the simulation of 10 temporal patterns per rainfall duration, thus taking into consideration the sensitivity of the catchment response to different combinations of front-loaded, mid-loaded and back-loaded rainfall events.

The key changes in flood levels can be summarised as follows and are shown in Figure 5.2:

- An increase in flood levels was observed at Lake Kurwongbah dam in all the analysed events. The increase ranged between 350mm and 470mm in the 5% AEP event, between 490mm and 620mm in the 1% AEP event, and between 370mm and 645mm in the 0.1% AEP event. This increase in flood levels is due to the change in peak timing related to the simulations of different temporal patterns when compared to the 2014 RFD simulations.

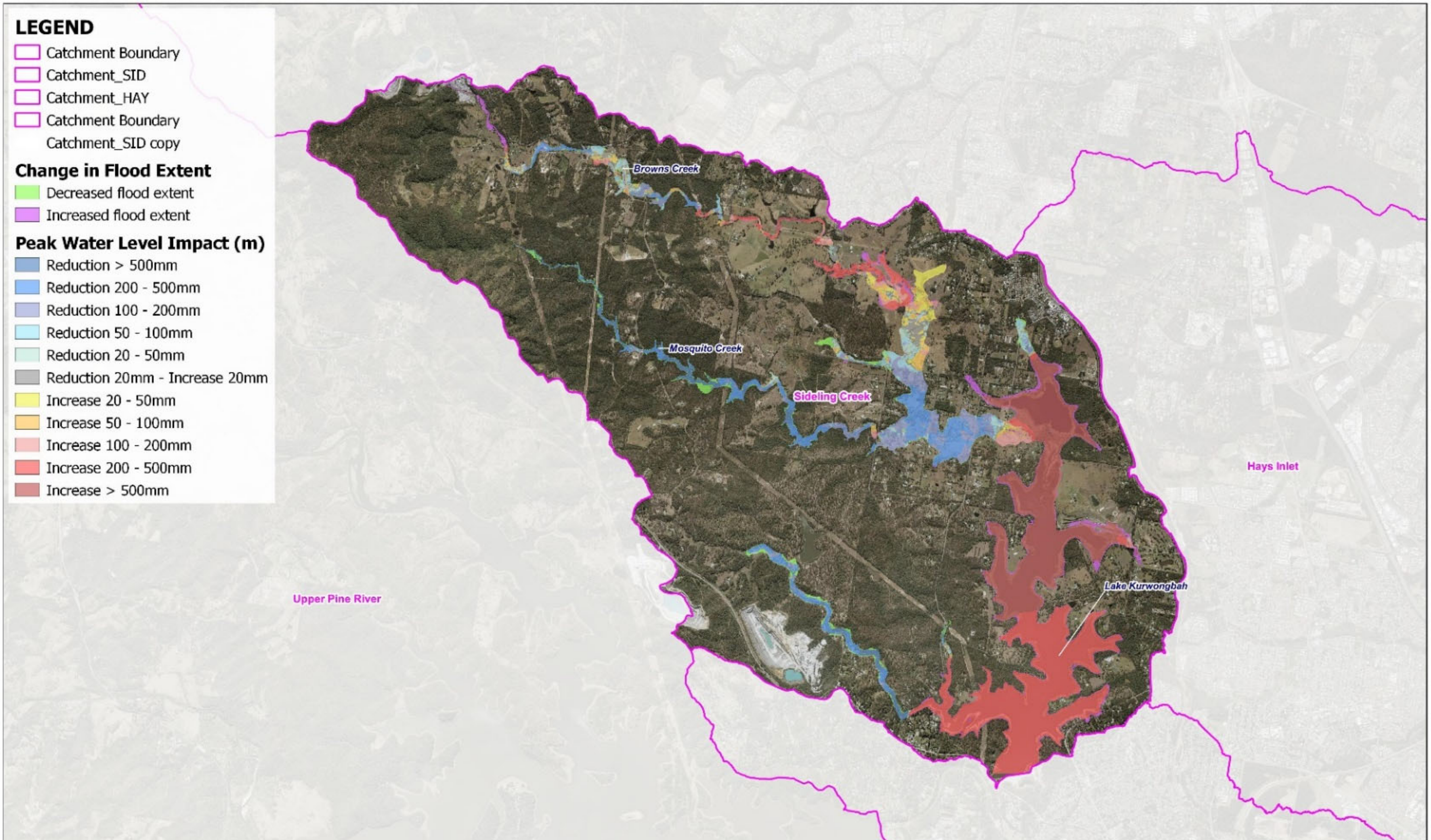
- A reduction in flood levels ranging between 20mm and 500mm is observed in the most upstream section of Browns Creek for the 1% AEP event. The location of inflow application along Browns Creek was moved further upstream in the 2022 RFD when compared to the 2014 RFD simulations, resulting in an increase in flood extent in the most upstream part of Browns Creek. The southern section of Browns Creek located downstream the Browns Creek Road crossing is mainly characterised by an increase in flood levels ranging between 100mm and 650mm in the 1% AEP event.
- An increase in flood levels ranging between 50mm and 855mm was mainly observed along Browns Creek in the 5% AEP event. Conversely, Browns Creek was characterised by a reduction in flood levels ranging between 20mm and 1m in the 0.1% AEP event.
- A reduction in flood levels was observed along Mosquito Creek. This reduction mainly ranges between 200mm and 1.2m in the 5%, 1% and 0.1% AEP events. In the 5% AEP event, some sections of Mosquito Creek experienced an increase in flood levels ranging between 50mm and 400mm. These sections are located upstream of Theodore Road crossing and in proximity of Bonnie View Court.
- A reduction in flood levels was observed along the south-western flowpath draining into Lake Kurwongbah. This reduction ranges between 20mm and 330mm in the 5% AEP event, between 100mm and 500mm in the 1% AEP event and between 200 and 900mm in the 0.1% AEP event.

The application of blockage factors to the culverts in the blocked scenarios produced higher flood levels upstream of the culverts and lower flood levels downstream of the culverts when compared to the unblocked scenarios, as expected.

2022 vs 2014 Future Conditions

The changes in flood levels between the 1% AEP future envelope of blocked and unblocked scenarios and the 2014 DFE MDS results were similar to the changes highlighted for the 1% AEP existing unblocked scenario. The following key changes were observed and are shown in Figure 5.3:

- An increase in flood levels ranging between 520mm and 635mm was observed at Lake Kurwongbah.
- A reduction in flood levels ranging between 20 and 560 mm was observed in the most upstream section of Browns Creek for the 1% AEP event, whereas an increase in flood levels ranging between 50mm and 590mm was observed in the southern section of Browns Creek.
- A reduction in flood levels ranging between 100mm and 1.2m was observed along Mosquito Creek.
- A reduction in flood levels ranging between 200mm and 780mm was observed along the south-western flowpath draining into Lake Kurwongbah.



Title:

1% AEP comparison 2022 vs 2014 (unblocked)

Figure: **Fig 5.2**

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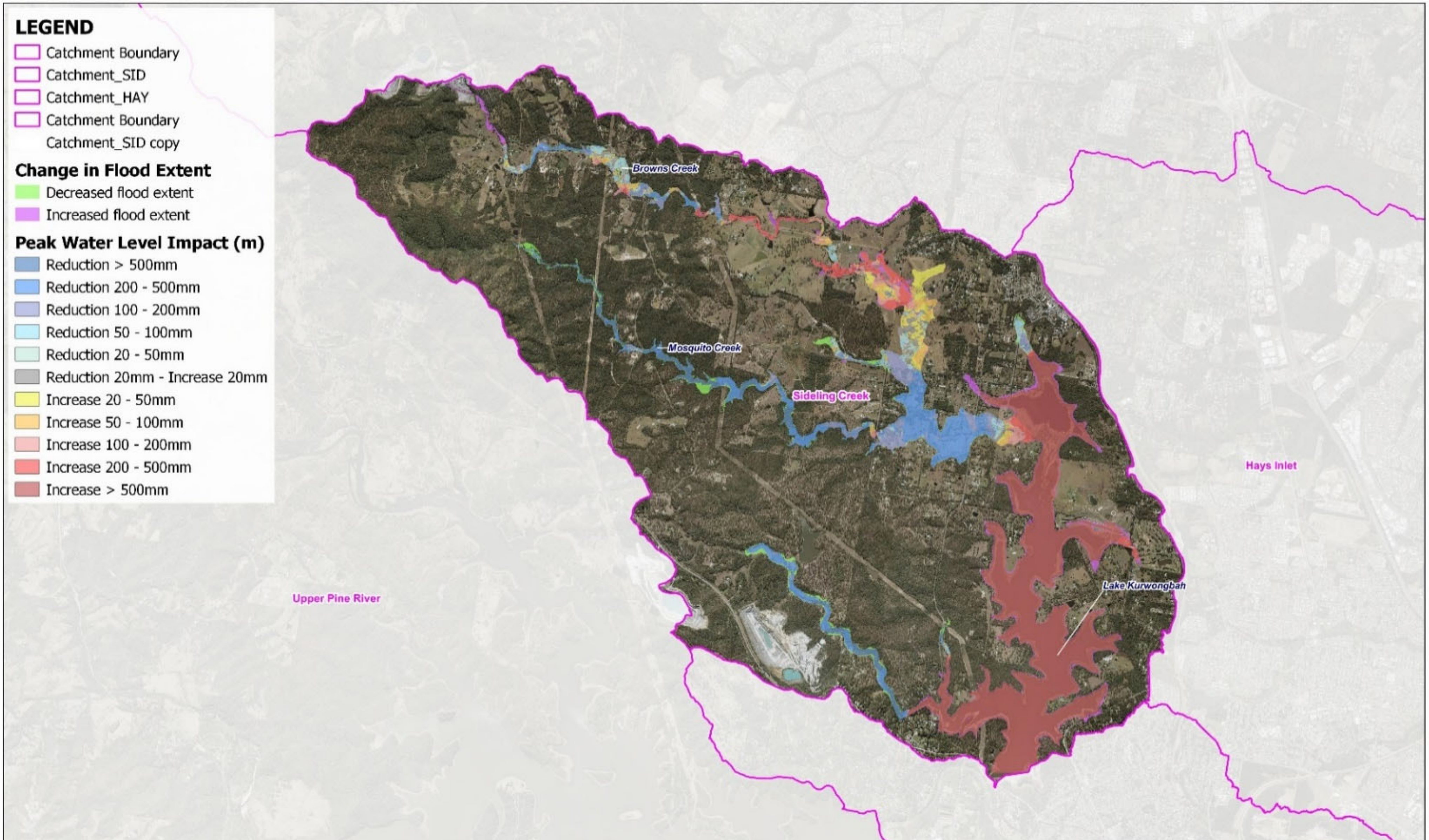

Title:
Comparison 2022 future 1% AEP vs 2014 DFE

Figure: **Fig 5.3** Rev: **A**

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5.4 Model Limitations and Quality

Watercourses within the Sideling Creek catchment were represented in the 2D domain, for which the grid resolution is 5m. This may not allow adequate representation of the channel conveyance particularly for smaller, more frequent flood events. In some instances, this limitation may lead to the model over or under estimating conveyance in the watercourses. The extent of this over or under estimation will vary according to local topographic features of the watercourses.

In consultation with MBRC, for each design event 3 different storms (durations and temporal pattern) were selected to be critical in the catchment. This reduced number of storms is practical in many ways; however, it is noted that due to the selection of the specific design events, the peak discharges and flood levels are in some locations overestimated or underestimated.

5.5 Model Specification and Run Times

Table 5.3 summarises the SID TUFLOW model run times and GPU memory requirements for various design events in the existing unblocked scenario. The longest storm durations among those modelled for each AEP event were chosen. It should be noted that the model run time is strongly dependent upon the machine's specifications and GPU card (i.e., 1080, 2080 or 3080). The SID TUFLOW models were simulated using the 2020-10-AC-iSP-w64 TUFLOW HPC executable.

Table 5.3 Model Specification and Run Time Summary

Event	Approximate Model Run Time	Required GPU Memory	GPU Card
20% AEP 12-hour	1.3 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
10% AEP 9-hour	1.3 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
5% AEP 9-hour	1.3 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
2% AEP 6-hour	0.7 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
1% AEP 6-hour	0.8 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
0.1% AEP 6-hour	0.8 hours	896 MB	NVIDIA GeForce RTX 2080 Ti
0.05% AEP 6-hour	0.9 hours	896 MB	NVIDIA GeForce RTX 2080 Ti

6 Conclusion

The Sideling Creek (SID) WBNM and TUFLOW models were updated, and model calibration and verification were undertaken to the 2022 and 2011 historic events.

It was noticeable that the amount of calibration data was limited in the SID catchment, in particular for the area upstream of Lake Kurwongbah. A very good match of the recorded and modelled hydrographs for the 2022 event was achieved at the Lake Kurwongbah gauge. It is recommended to install additional rainfall and stream gauges and gather additional data (survey flood marks post flood events) in this catchment to improve model calibration. More comprehensive data will be advantageous to improve flood model calibration in the SID catchment and there is an added benefit because the outflows from this catchment inform the downstream area, the Lower Pine River and Hays Inlet catchments (LPH). Hence improved model calibration in SID will also improve the certainty of inflows to the LPH model.

An HEH model was developed for the Sideling Creek catchment using WBNM. The purpose of the HEH model is to ensure consistency (hydraulic equivalence) with the TUFLOW model. The HEH model can then be used in place of the TUFLOW model for identifying critical events and temporal patterns for design flood modelling.

The HEH methodology was originally developed in Council's pilot study and BMT has since updated this methodology to utilise the stream lag factor to a greater degree and reducing the number of artificial storages required. The hydrographs of the WBNM and TUFLOW models were compared for 4 events and 3 durations per event using ARR 1987, to cover a range of events and flows in the catchment. A scoring system was developed to assess the degree of matching between the WBNM and TUFLOW hydrographs at the nominated points of interest (HEH points). The scoring considers the time peak discharge, the peak ratio between the WBNM and TUFLOW model and the shape of the hydrograph using Nash-Sutcliffe calculations (refer to Annex C for more details).

Application of this methodology and scoring system demonstrates a good match between the WBNM and TUFLOW hydrographs for the majority HEH points within the Sideling Creek catchment. For most of the HEH points (80%) an 'excellent' score was achieved with all other points categorised as 'good' across the Sideling Creek catchment. The developed HEH models are considered to be an improvement to the 002c hydrologic models because of improved timing throughout the hydrograph and matching the peak flow.

The HEH models were considered fit for purpose to undertake Stage 5, the design modelling stage.

A detailed design selection process was undertaken initially with the focus on the results from the WBNM HEH peak discharges (refer to 0 for more details). For each design event 3 different storms (durations and temporal pattern) were selected to be critical in the catchment in consultation with MBRC. This is a significantly reduced number of model simulations, which is practical in many ways, including future modelling to inform flood impact assessments for future development and infrastructure. However, it is noted that due to the selection of the specific design events, the peak discharges and flood levels are in some locations overestimated or underestimated.

Based on the methodology, including model calibration/verification and the development of the HEH models, as well as the results and comparison to 2014 model the SID models are considered fit for purpose for use in floodplain planning and flood forecasting.

Although the model is a significant update and improvement to the previous modelling and considered fit for purpose, some recommendations for improvements can be undertaken in future model updates:

- Recommendations for hydrologic modelling:
  - Develop Flood Frequency Analysis (FFA) at gauges for further validation of design event results noting that a number of years of recorded flows/levels are required.
  - Perform further investigations into pre-burst rainfall values based on the gauges located in the catchments as opposed to using ARR 2019 Data Hub pre-burst values. These changes in pre-burst values may in turn inform updates to the initial water levels in the reservoirs adopted as a starting point for the burst design event simulations.
  - Reconcile the design event rainfall losses across the whole MBRC LGA.
  - Refine the buckets for temporal patterns and ARFs based on the critical storms in each bucket. At present, the adopted buckets are limited by the ARF calculated for the 1% AEP 1-hour event.
  - Keep up-to-date dam control rules in the models in light of any changes in dam controls.
- Recommendations for hydraulic modelling:
  - Collect more reliable bathymetry data for the dam reservoirs.
  - Simplify the blockage assessment by removing the inlet/outlet control assessment for the assignment of culvert blockage. It is noted that the inlet/outlet control conditions change during the same storm simulation, between different storms for the same AEP event, and also between AEP events. The use of different blockage factors/ modified inlet losses can lead to inconsistencies in flood levels between AEP events for the blocked scenarios.
  - Consider the number of barrels per culvert in the calculation of blockage factors. At present, the blockage factor is calculated for each single culvert, however, this approach can be considered overly conservative and an underestimation of the flood levels downstream of the culverts in the blocked scenarios.
  - Adopt latest TUFLOW HPC software release to use additional features, such as Quadtree, SGS and high-resolution map outputs.
  - Switch to Quadtree to use coarser grids on rural areas and finer grids in proximity of dwellings to optimise model runtimes without compromising the quality of the model results.
  - Consider the use of output zones to save results in the areas of interest. Different types of maximum grids and/or model results can be saved only in these areas and with a higher temporal resolution, thus avoiding large amount of computational memory on areas of non-interest.
  - If there is an interest in riverine water quality modelling,
    - Acquire high-resolution topographic and bathymetric data in the creeks to improve the simulation of low flows.
    - Install water quality gauges in the catchments to inform future riverine water quality modelling.

Annex A Model Calibration: SID Catchment

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Technical Note

Project	RFD 2021 Major Update		
From:	Anne Kolega, Charmaine Machikiti (BMT)		
Date:	17/03/2023	To:	Hester van Zijl (MBRC), Bonnie Beare
Doc Ref:	T.A11567.016_Model_Calibration_SID		
Subject:	Model Calibration: SID Catchment		

1 Introduction

This technical note documents the model calibration and validation undertaken for the Sideling Creek (SID) catchment. It includes a summary of available data, along with presentation and discussion of the results.

The SID catchment has been calibrated to the event of February 2022 and validated to the event of January 2011 using the SID WBNM model and TUFLOW HPC model without the sub grid sampling (SGS) feature and a grid resolution of 5m.

Of these two events, the February 2022 event was the larger event. For both events there is limited calibration data available.

Table 1.1 summarises the events modelled.

Table 1.1 Modelled Events: SID

Event	Model Start	Model End	Simulation Period (h)	Accumulated Rainfall during the event at Lake Kurwongbah
January 2011	9/1/2011 00:00	12/1/2011 01:00	73	1000mm
February 2022	25/02/2022 02:00	28/2/2022 06:00	76	550mm

2 Available Data

2.1 Rainfall Data

Event rainfall data has been sourced from available stations. Table 2.1 lists the gauges available for each event considered. The gauges are shown in Figure 2.1.

The rainfall gauges are used to assign both rainfall depths, using Thiessen polygons, and temporal patterns to the model.

Cumulative plots of rainfall depth at gauges for each event are provided in the event specific section of this technical note.

Table 2.1 Rain Gauges - SID

Gauge Name	Gauge ID	2011	2022
Browns Creek Road AL	540411		✓
Dayboro WWTP AL	540484	✓	
Lake Kurwongbah AL	540204		✓
Moorina AL	540358	✓	✓
Youngs Crossing AL	540412	✓	

2.2 Stream Gauges

No stream gauges, recording event water levels in the SID catchment were available for the 2011 or 2022 events except the recorded water level in Lake Kurwongbah for the 2022 event. The recorded water level in the lake has been used to compare against modelled results for the 2022 event by assessing the match to flood peak, timing, volume and hydrograph shape. Table 2.2 lists the available data.

Table 2.2 Available Stream Gauges

Gauge Name	Gauge ID	Watercourse	2011	2022
Lake Kurwongbah AL	540204	Sideling Creek		✓

For both the January 2011 and the February 2022 event, the outflow from the Lake Kurwongbah Dam was provided. As there is no available recorded water level in the lake for the 2011 event, the modelled dam level has been compared to the recorded dam releases for that event.

Title:

Rainfall and stream gauges used for SID calibration

Figure: **Fig 2.1**

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2.3 Surveyed Flood Marks

Council has undertaken post event surveys of debris marks which indicate the peak height of the respective flood events. These flood marks are compared to the modelled peak flood level. The quality of the flood mark can vary. They can be relatively accurate if determined from a maximum height gauge or clearly defined peak water level mark eg on the side of a building. Others will be subject to a greater degree of uncertainty, for example debris may have lodged lower than the maximum water level or may reflect local hillslope runoff rather than main river levels.

Notwithstanding the above uncertainties, flood marks, when collected in sufficient quantities, can provide a valuable overview of peak flood levels as greater confidence can be placed in the surveyed elevations when they corroborate with each other. For example, a cluster of flood marks in close spatial proximity, all giving similar elevations provides a high degree of confidence that the floodwaters reached that elevation.

Where available, calibration performance against flood marks has been presented both spatially on maps and graphically as histograms.

For the SID catchment, 21 flood marks were surveyed following the January 2011 event. These are all rated as having a 'medium' indicative quality. No flood marks were recorded following the February 2022 event in the SID catchment. Table 2.3 lists the number of available flood marks in the SID catchment by event.

Table 2.3 Flood Marks

Event	Number of flood marks	Number of flood marks used
2011	21	18
2022	0	0

Three flood marks in total were excluded from the analysis (SID010, SID011 and SID015). Two flood marks were noted to be a distance (around 200m) from the flood extent and the third had a significant difference in height. These were removed from the analysis as it is likely these captured localised overland flow on flow paths not captured by the regional model.

3 February 2022 Calibration Event

3.1 Event Rainfall and Dam Releases

The February 2022 event was a relatively long duration event with persistent heavy rainfall across a three-day period. The heaviest falls occurred on the last day of the event (27 February). Event rainfall totals ranging between 800mm and 1000mm were recorded at the three gauges in proximity to the SID catchment. Cumulative event rainfall at these three gauges is shown in Figure 3.1.

A peak dam outflow of 515m^3/s occurred during the event.

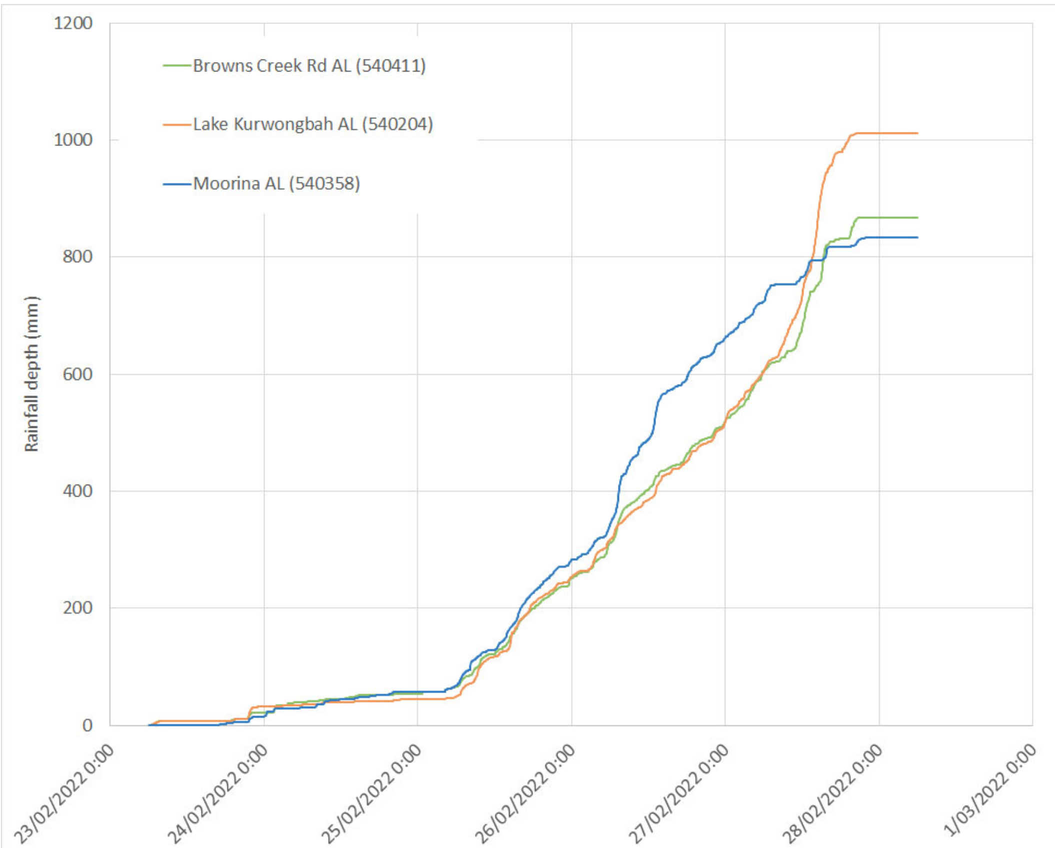
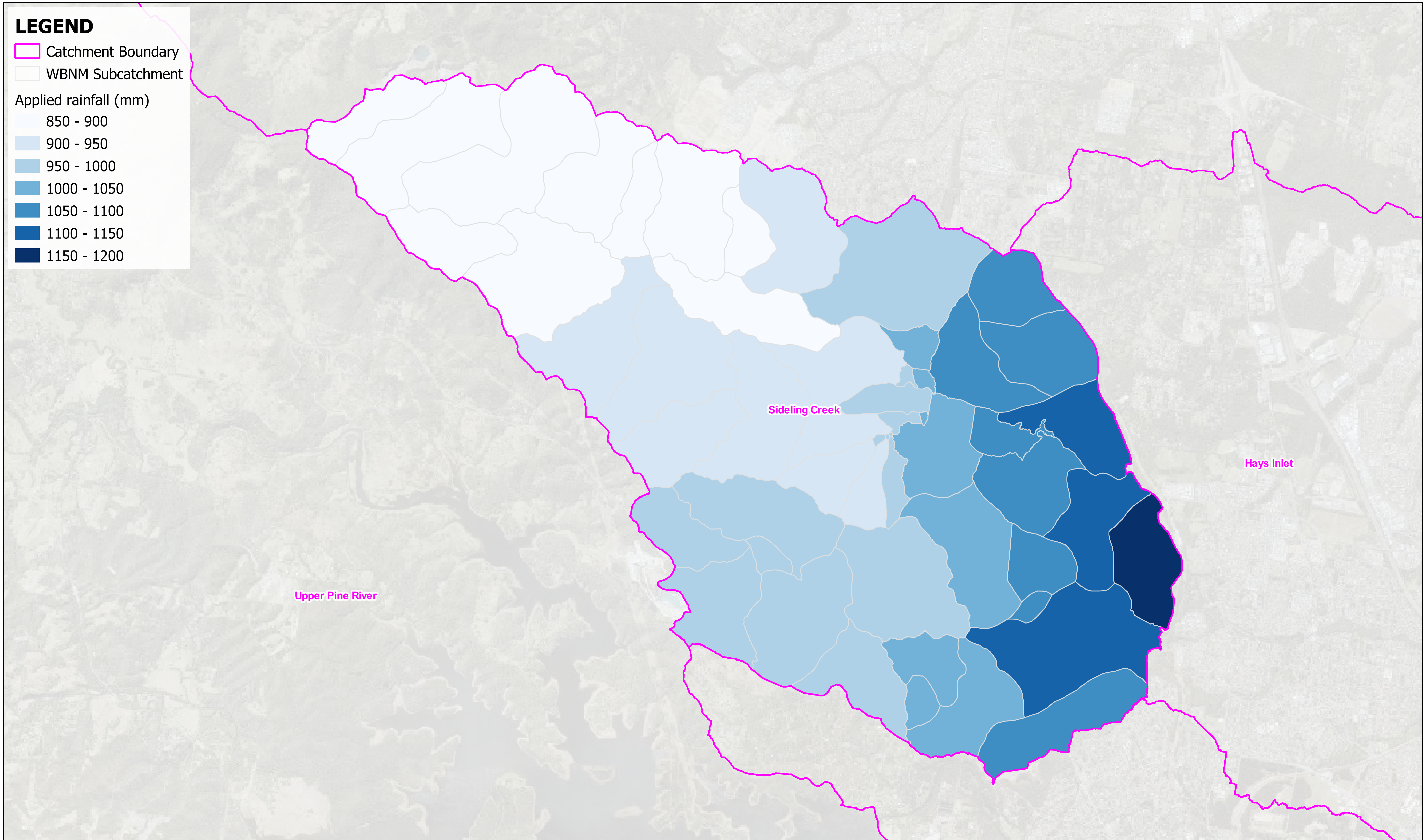


Figure 3.1 February 2022 Event: Cumulative Rainfall Plot



Title:
February 2022 Event Rainfall applied in model

Figure: Fig 3.2

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3.2 Calibration Results and Discussion

Rainfall loss values of 60 mm initial loss and 1.0 mm/h continuing loss were adopted for the 2022 event calibration. Figure 3.3 plots the modelled and recorded water levels in Lake Kurwongbah. No flood marks were available in the SID catchment for the February 2022 event.

The calibration shows that the timing and shape of the water level in Lake Kurwongbah is replicated very well in the model. There is a slight and relatively consistent offset in the modelled and recorded heights. Upon investigation it appears that the rating curve for the dam spillway which is applied in the model is slightly different to the actual spillway rating. This was established by examining recorded outflows and levels and comparing the relationship to the modelled rating curve. For a given recorded level, the modelled rating results in a higher dam outflow than that shown in the recorded data. BMT has requested an updated spillway rating curve and the model will be updated with this once made available. Given that the calibration still shows a close match to the recorded dam levels no manual attempt has been made to adjust the rating.

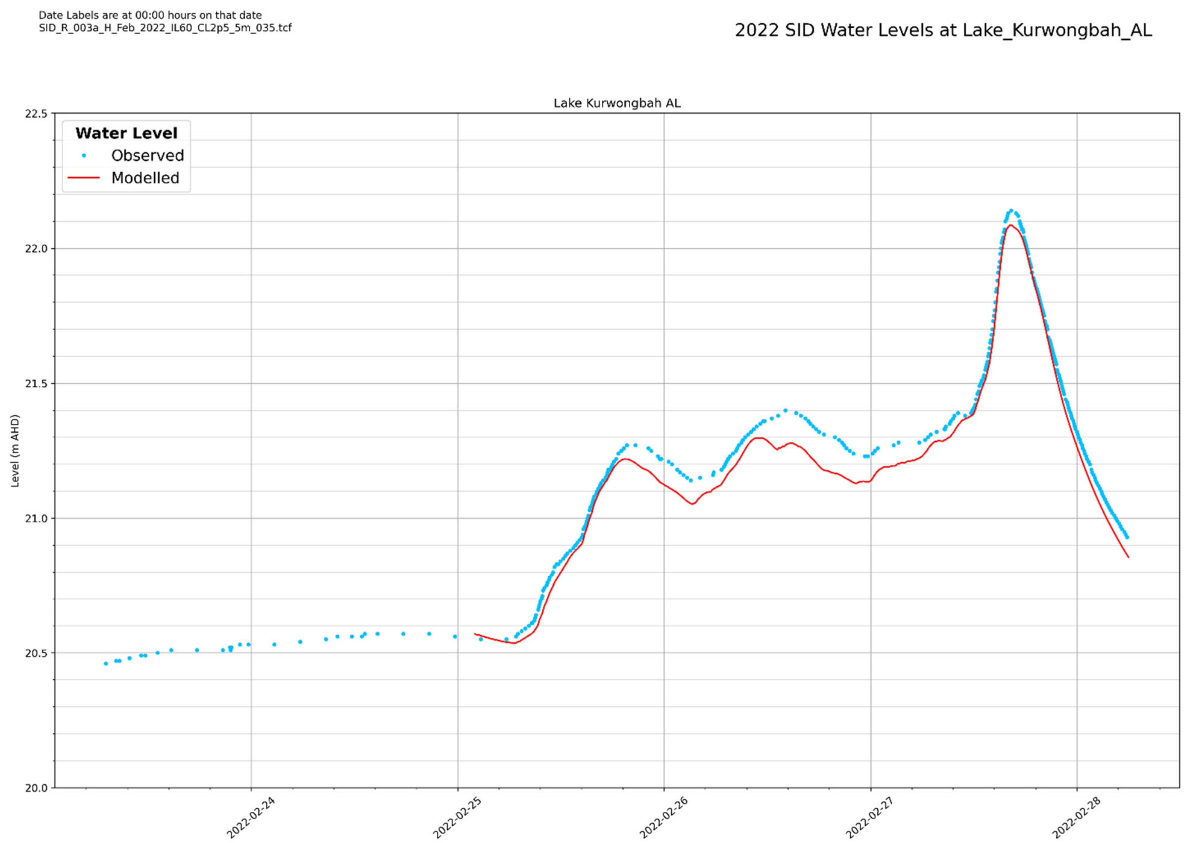


Figure 3.3 Plot of February 2022 Event Modelled and Recorded Water Levels in Lake Kurwongbah

4 January 2011 Verification Event

4.1 Event Rainfall

The event of January 2011 occurred on the back of above average rainfall within South East Queensland. It is characterised by two periods of heavy rainfall with the second period, which occurred on 11 January, being the most intense.

Total rainfall depths ranging between 280mm and 570mm were experienced across the SID catchment.

Figure 4.1 shows the cumulative plot of rainfall at available gauges. Figure 4.2 shows the distribution of rainfall applied in the WBNM model.

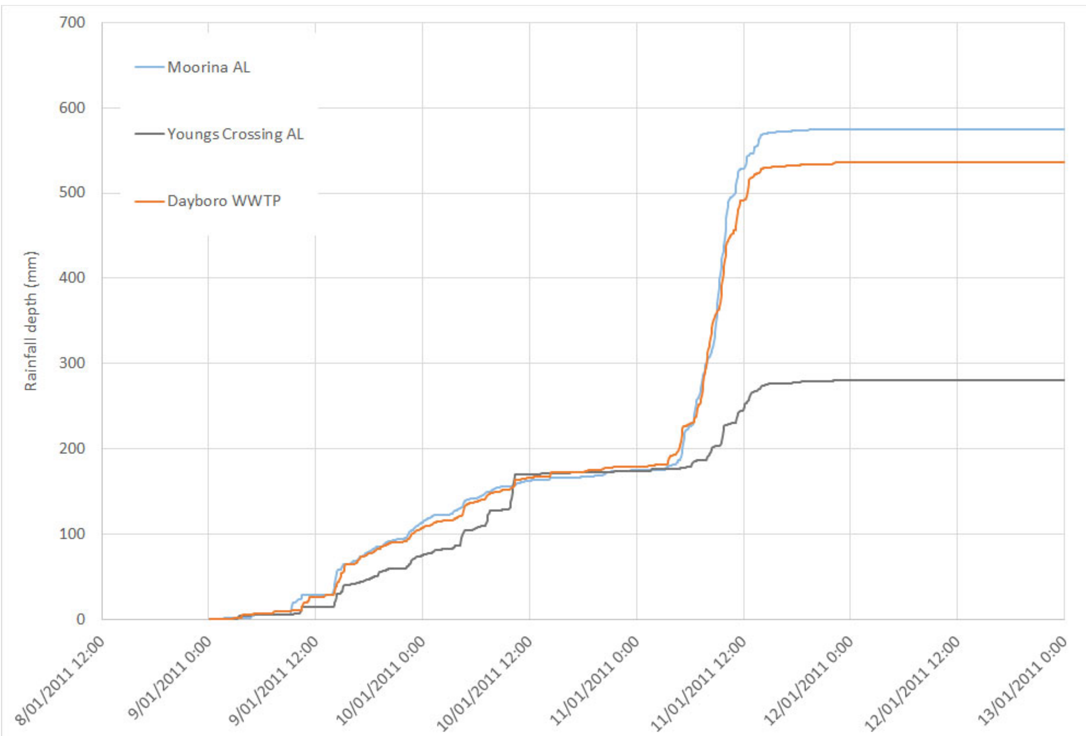
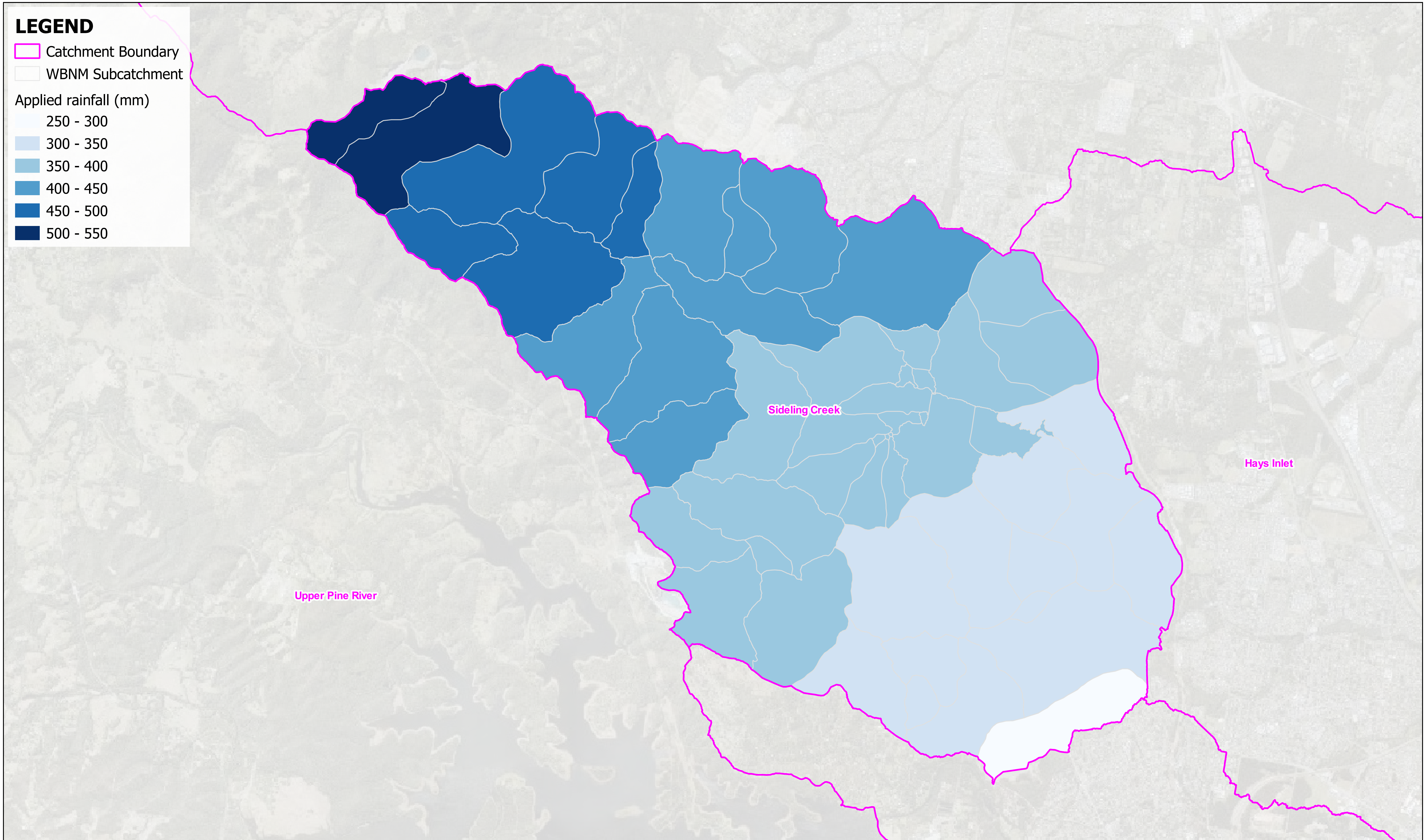


Figure 4.1 January 2011 Event: Cumulative Rainfall Plot



Title:

January 2011 Event Rainfall applied in model

Figure: **Fig 4.2**

Rev: **A**

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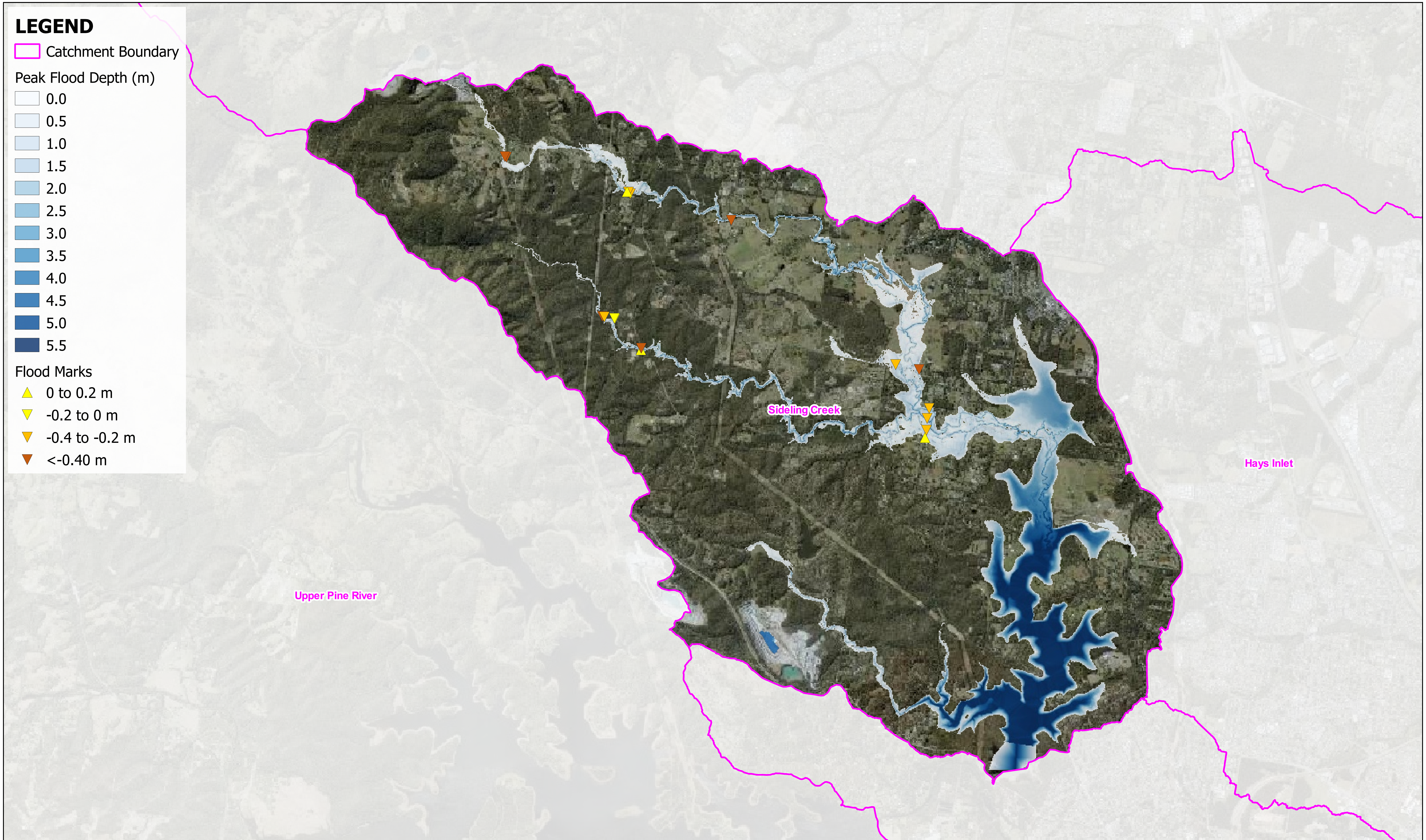
4.2 Calibration Results and Discussion

Rainfall loss values of 10 mm initial loss and 1.0 mm/h continuing loss were adopted for the 2011 event verification. No recorded water levels at gauges were available in the SID catchment for the 2011 event. A total of 21 flood marks are available and have been compared to the model results. These are presented as follows:

- Figure 4.3 shows the difference in peak level (modelled result minus recorded value) at flood marks
- Figure 4.4 presents a histogram of differences between modelled and recorded values at flood marks.

Key summary points noted from the results are provided below:

- At the majority of flood marks the modelled result appears too low. This is despite the application of low rainfall loss values. The underprediction of flood levels is likely due to the limited rainfall data available for this event. The lower rainfall depths recorded at the Young's Crossing gauge maybe having too great a moderating factor on the higher totals likely experienced in higher parts of the catchment. A sensitivity test was undertaken by removing the Young's Crossing gauge from the rainfall, leaving reliance on the Moorina and Dayboro WWTW gauges to inform rainfall depths and patterns. The results showed an improved match to the flood marks but the resulting peak level in Lake Kurwongbah was significantly too high for the recorded outflow.
- A total of three flood marks were removed as mentioned in Section 3.2 above.
- A plot of the recorded dam outflows for the 2011 event along with the modelled dam level shows good agreement on the timing. Two notable recorded periods of outflow correspond to two periods of modelled elevated lake water levels.



Title:

January 2011 Calibration to Flood Marks

Figure: **Fig 4.3**

Rev: **A**

BMT

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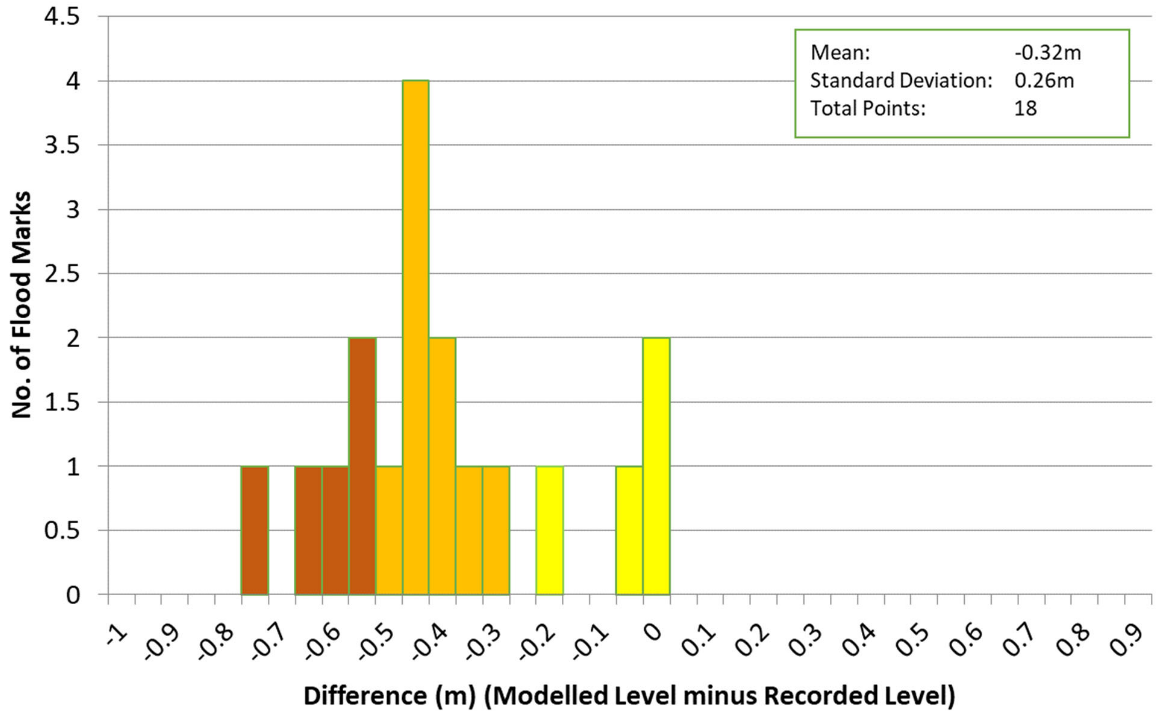

Figure 4.4 January 2011 Event: Histogram of Differences in Level to Flood Marks

5 Conclusions

Overall, the calibration and validation of the SID catchment to historical events is considered satisfactory although there is limited available calibration data. Modelling of the February 2022 event demonstrates that the model is able to adequately simulate the catchment runoff response into Lake Kurwongbah throughout the event and in particular during the peak of the event.

There is greater uncertainty with regards to calibration in the catchment area upstream of Lake Kurwongbah as there are no water level gauges and peak flood marks are only available for the January 2011 event, for which there is limited rainfall data. It is recommended to install additional rainfall and stream gauges and gather additional data (survey flood marks post flood events) in this catchment to improve model calibration. This will also benefit the modelling in the LPH model because it uses inflows from the SID model.

Annex B HEH Modelling Methodology

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Technical Note

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

Overview

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

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

Aim

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

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

[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.

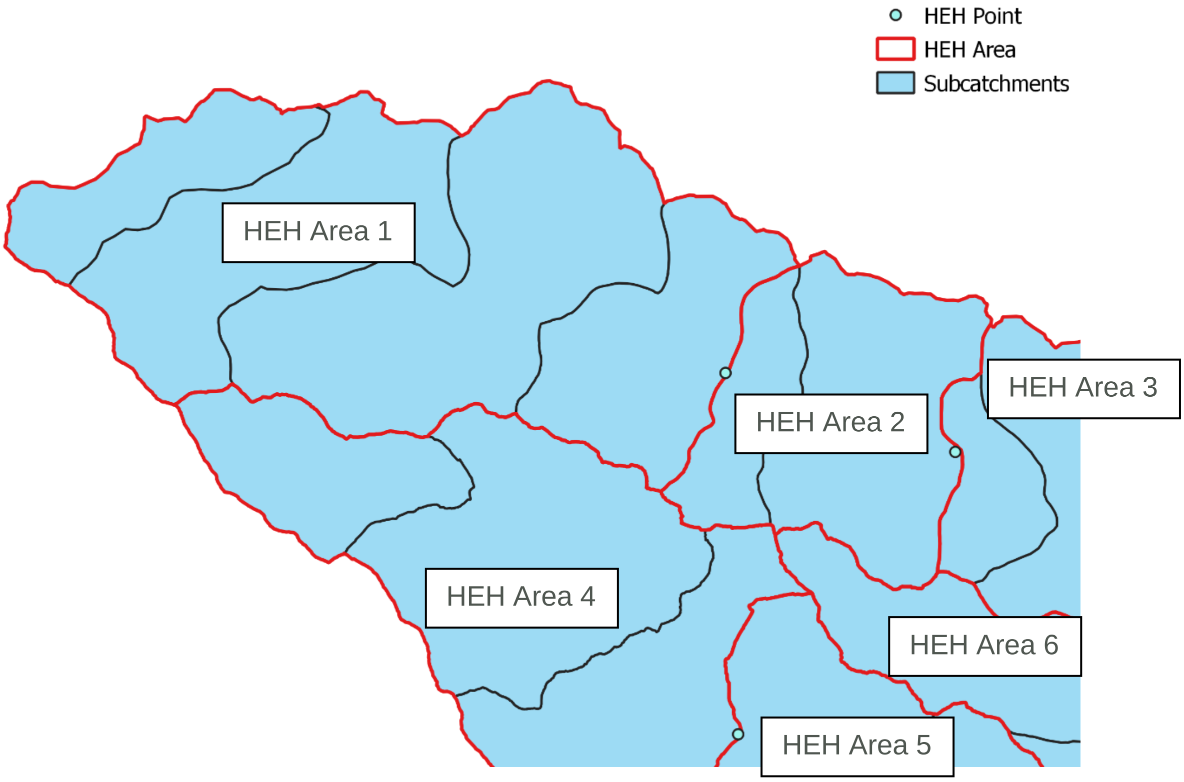

Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

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).

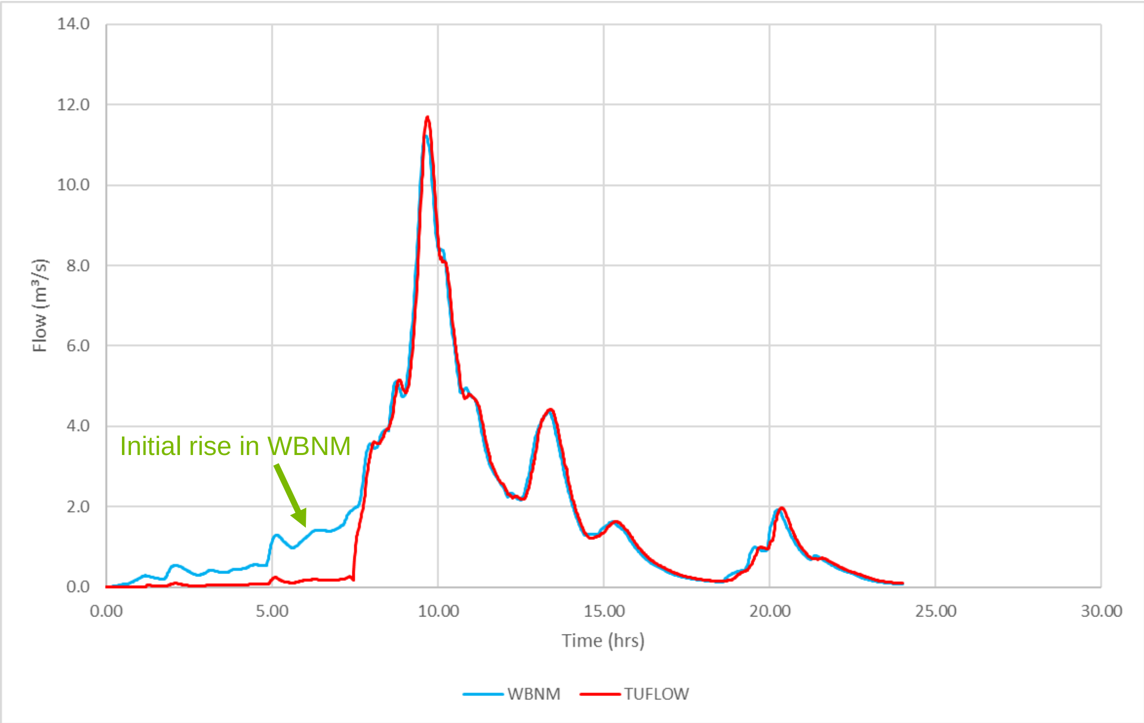

Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

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

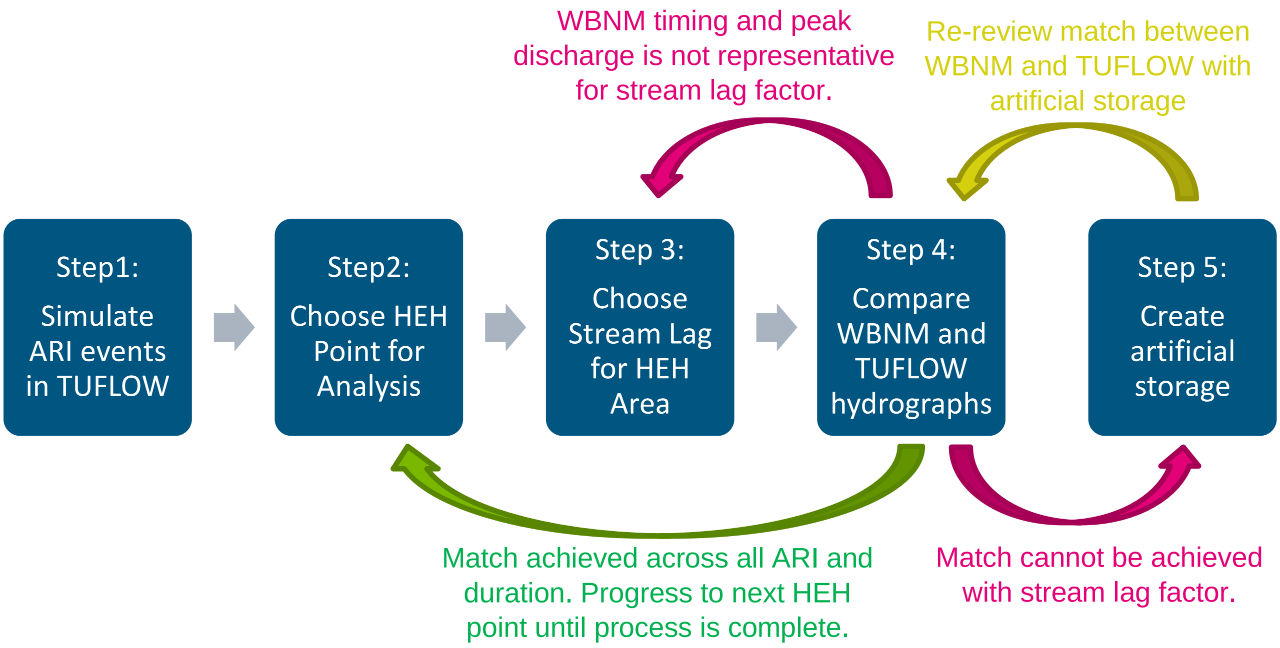

Figure 1.3 Flow chart for the HEH model methodology

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.

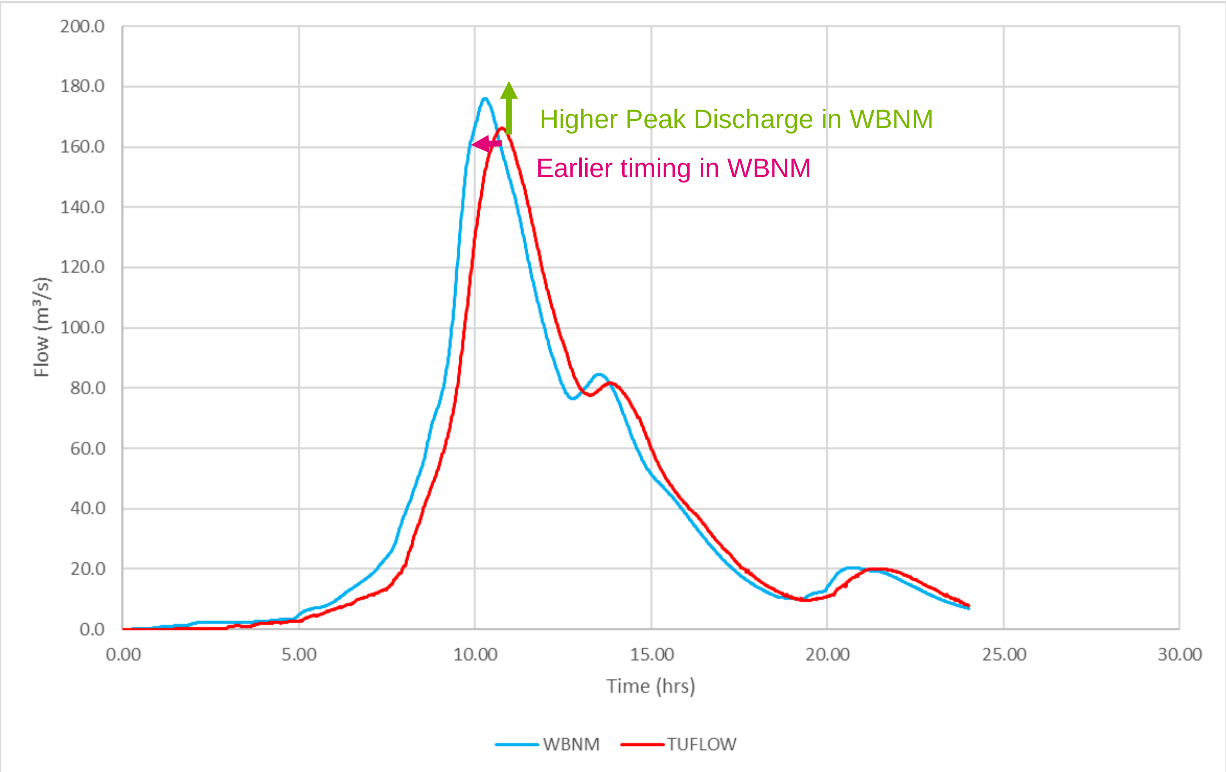

Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

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:

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

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

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

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

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

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

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

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

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

Figure 1.5 Calculation of Storage

The ideal storage curve for each individual temporal pattern and ARI is where the storage increases with flow on the rising limb to the peak discharge[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.

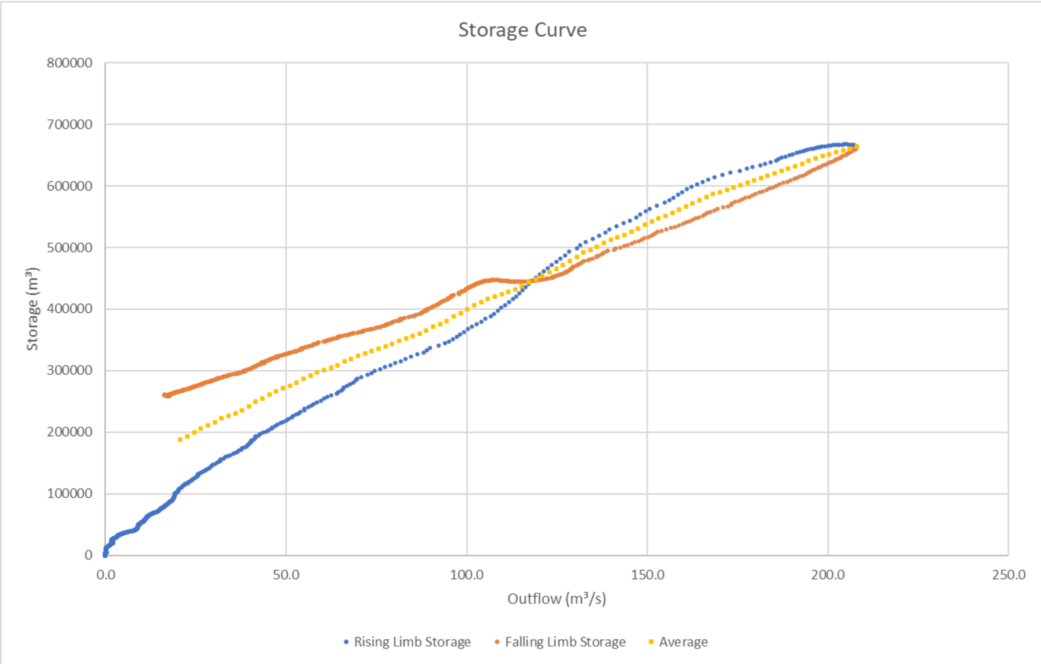

Figure 1.6 Ideal Storage-Outflow Curve

Light green dots result in
a curve which is not ideal

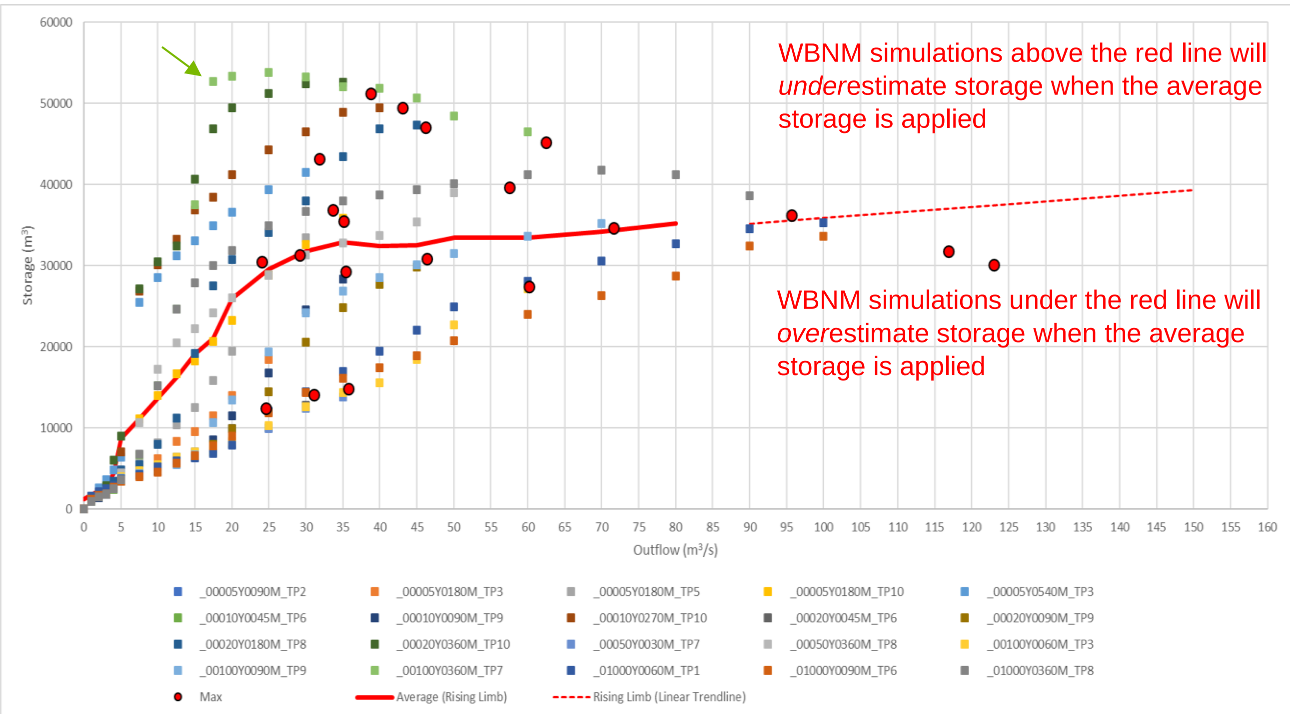

Figure 1.7 Example of an averaged S-Q curve (storages extracted from the rising limb of each duration and ARI)

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.

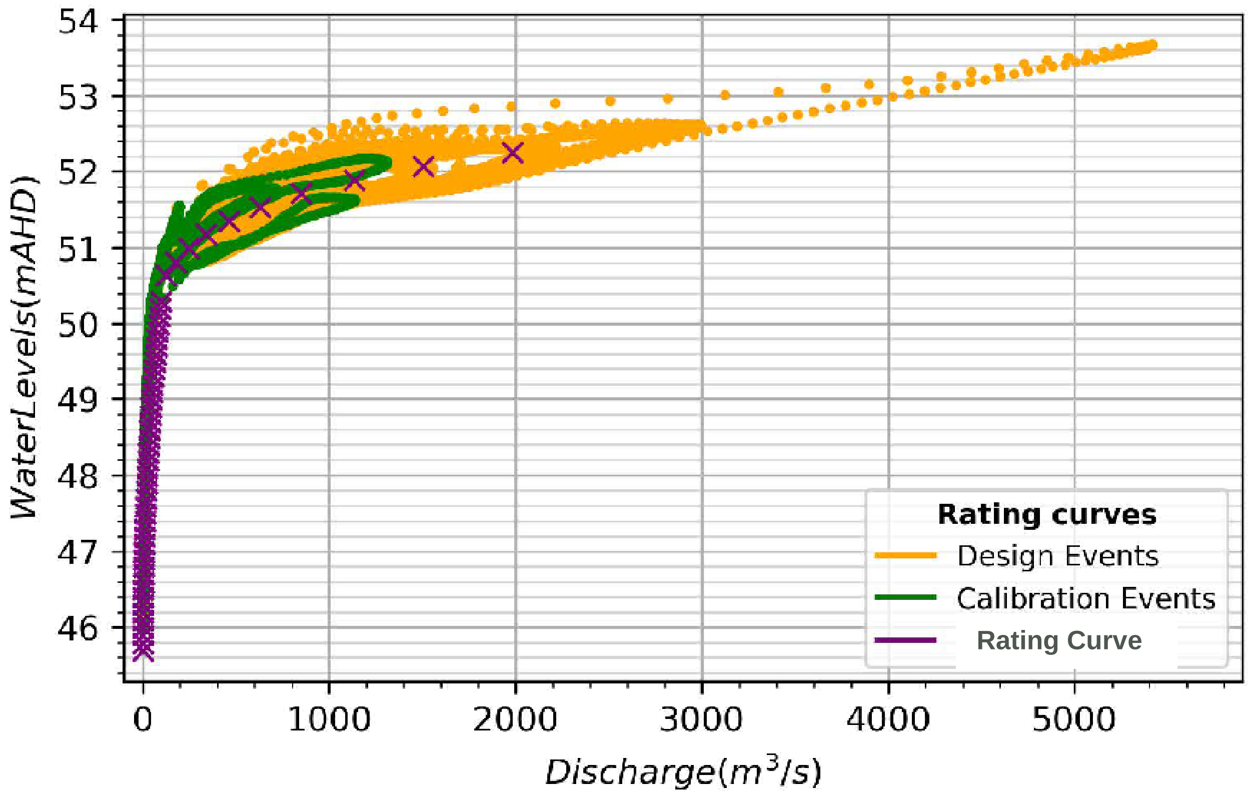

Figure 1.8 Rating curve with hysteresis

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

Annex C Sideling Creek HEH Modelling and Results

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Technical Note

Project	A11567 – RFD 2021 Major Update		
From:	Blair Filer		
Date:	11/04/2023	To:	Hester van Zijl (MBRC)
Doc Ref:	T.A11567.017		
Subject:	Sideling Creek HEH Modelling and Results		

Overview

This Technical Note has been prepared to outline the implementation and results for the Sideling Creek hydraulically equivalent hydrology (HEH) model undertaken as part of the RFD 2021 Major Update. The aim of the HEH modelling 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 catchment. The match of hydrographs has been considered in respect to peak discharge (peak ratio), 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. A full detailing of the adopted HEH methodology is contained with a separate technical note prepared by BMT.

The purpose of the HEH (WBNM) model is to select 'critical' temporal patterns and durations in the hydrology model when applying the latest Australian Rainfall and Runoff (ARR2019) guideline. This selection process will limit the need to simulate all temporal patterns and durations for each annual exceedance probability (AEP) design event in the hydraulic model leaving just the 'AEP neutral' simulations. This process therefore provides a more efficient procedure in temporal pattern and duration selection whilst retaining a desired level of accuracy.

The HEH modelling initially uses WBNM's stream lag factor as a primary source of 'matching' the hydrologic hydrograph with the hydraulic one. 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.

The RFD 2021 Major Update project describes 'points of interest' (POI). POI include both HEH points where there hydrologic/hydraulic match is assessed as well as design event modelling points to assist with design event selection when using ARR2019 methodology. To avoid confusion this technical memorandum refers to POIs by their subclassification i.e HEH point or design event modelling point.

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.

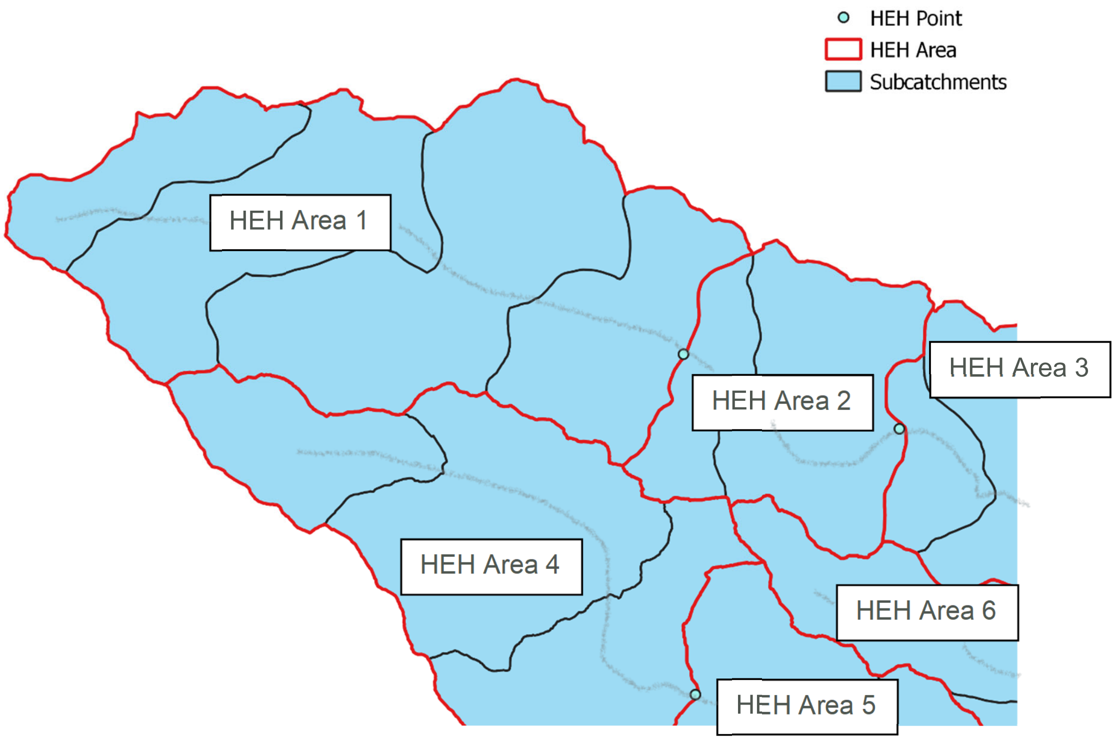


Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

1.2 Definitions

The definition used throughout this technical document are as follows:

- 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.
- Nash-Sutcliffe Efficiency – the calculated error variance ratio of the modelled (WBNM) time-series divided by the variance of the observed (TUFLOW) time-series.
- Peak Ratio – the calculated percent ratio of the modelled (WBNM) peak discharge to the observed (TUFLOW) peak discharge.

1.3 Document Setup

The remainder of this Technical Note includes the following sections:

- HEH Point Nomination – this section details the selection process for defining HEH points across the catchment.
- HEH Implementation – this section contains additional detail from that documented in the methodology technical note in order to implement the HEH modelling practically within the subject minor basin.
- WBNM HEH Model – the results at each HEH point are presented in this section for the final HEH model.

2 HEH Point Nomination

MBRC supplied initial suggested points of interest (POI) at the start of the RFD 2021 Major Update project. These POI have been reviewed, refined, and expanded by BMT during this project for the purposes of undertaking the HEH modelling and the ARR2019 Design Event selection. The review of the POI ensured that confluences, roads, future development area, gauges, and catchment outlets were considered in the nomination of the POI. The POI were then divided into 'HEH points' for establishment of the WBNM HEH model and 'Design Event Modelling' points. Both sets of POI are shown in Figure 2.1 with the most notable differences between the two sets are as follows:

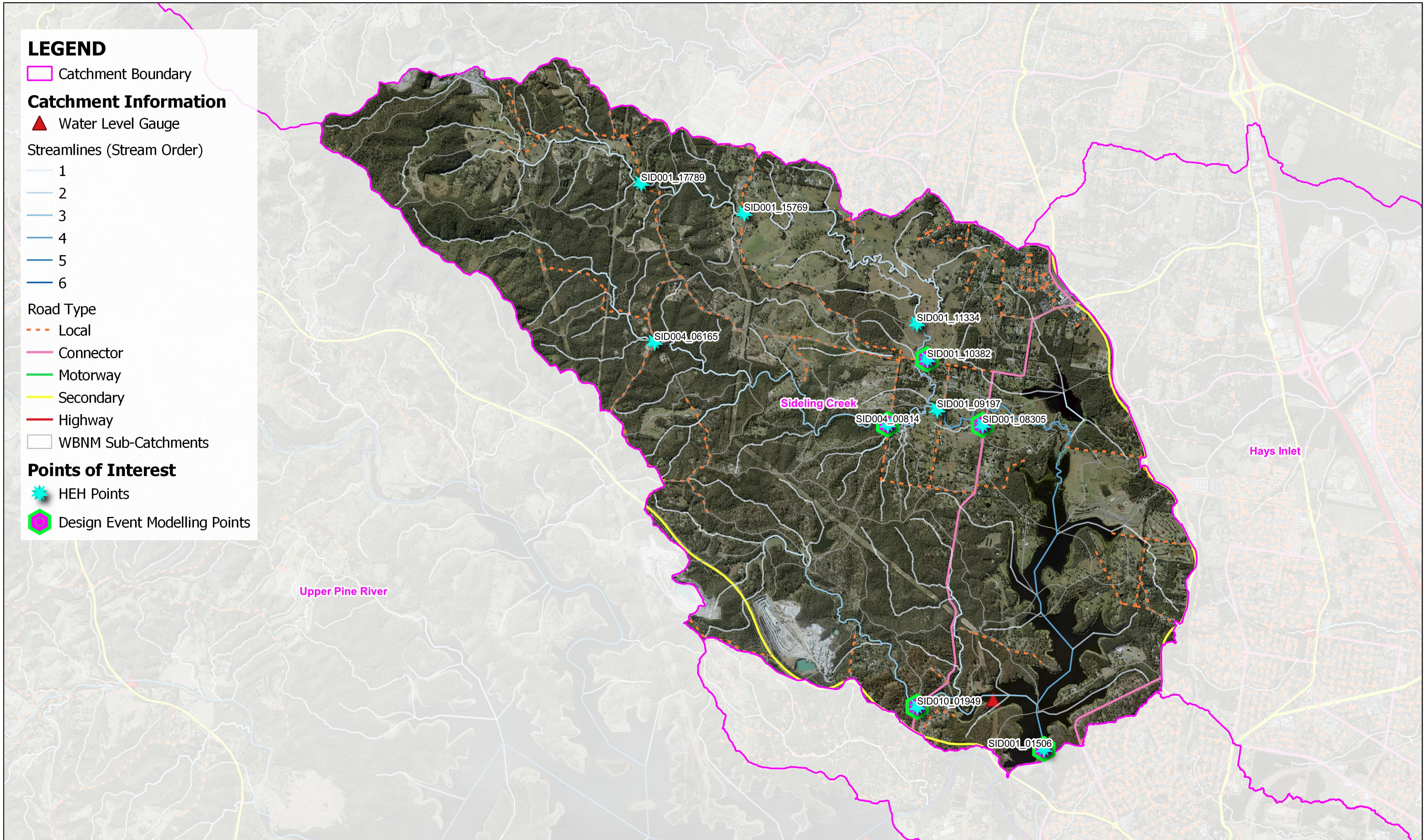
- HEH points –
  - Confluences – the points are located in each respective tributary (i.e. upstream of the confluence). Matching flow within each respective tributary allows the flow at the downstream confluence to be modelled more accurately.
  - Rural Areas – the points are located at local roads which cross significant streams in rural areas.
  - HEH points are not established on a downstream POI if the sub-catchments are within two sub-catchments of one-another. The underlining assumption is that the timing and peak discharge will not significantly change over two sub-catchments.
- Design Event Modelling points –
  - Confluences – the point is located at the confluence. This allows capture of the total flow to that confluence. Note that if a major road is located on one or both tributaries these additional locations will also be included as design event modelling points.
  - Rural Areas – only major roads crossing streams were selected.

To nominate the POI, the following GIS information was used:

- Streamlines -
  - a stream order 2 and above was used to establish the HEH points near confluences and local roads in rural areas.
  - a stream order 1 and above was used to establish all POI for future developments
- Roads - HEH points at local road were only established in rural areas. All major roads (Connectors, Highways, Motorways, and Secondary) had POI across the catchment.
- Water level gauges – POI near / at water level gauges were established.

For Sideling Creek minor basin, 10 HEH points[1] and 5 Design Event Modelling points were created (10 POI in total). The labelling of the POIs is based on the sub-catchment ID in which the POI falls.

[1] To ensure consistency of the stream lag factor, BMT has also reviewed additional points within each HEH area. Where consistence was not achieved BMT changed the location of the HEH point. A further 14 undocumented points were reviewed for SID.



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Points of Interest

Figure: **2 - 1**

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BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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3 HEH Implementation

3.1 Further Details to Framework

Further specific details with regard to the steps involved in the implementation of the HEH methodology are summarised in Table 4.1.

Table 3.1 Further Details when Implementing HEH model development

Step	Comment
1	The following ARI events and durations were simulated through the TUFLOW model[2]: • ARI events– 5-year, 20-year, 100-year, 2000-year • Durations – 60-minute, 120-minute, 360-minute
2	HEH points were ordered so that multiple HEH points could be reviewed simultaneously.
3	Multiple models were setup to run consecutively with different stream lag factors. The models started with a stream lag factor of 0.2 and incremented up by 0.05 to a final stream lag factor of 1.25 (22 simulations in total).
4	The following was undertaken for comparison: • The WBNM outputs were interpolated to match the TUFLOW output interval of 5-minutes • WBNM total flows at confluences were combined. • At culvert locations, where TUFLOW contains both flow in 1D and 2D domains, the 1D and 2D flows were combined. • A scoring system was implemented to assess the best outcome from all the stream lag factors simulated in Step 3, or after the artificial storage implemented in Step 5. This scoring system is described in Section 3.2
5	The artificial storages were implemented based on the following: • To apply an artificial storage at confluences, an additional dummy sub-catchment with zero area was included where a common sub-catchment combining the tributary discharge was not included in the supplied sub-catchments. • All simulated stream lag factors in Task 3 were assessed against the ideal WBNM hydrograph for the application of artificial storage in Figure 3.1. 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. The largest stream lag with the most ideal WBNM hydrographs was selected. • The artificial storage was applied using either of the two methods below: - A statistical analysis of the individual event / duration storage calculations. The statistical analysis is then extrapolated out to higher nominal outflow positions. An example is shown in Figure 3.2 with the orange dots being the individual storage calculations and the solid lines being the statistical analysis from the orange dots. This method is summarised according to the statistical method used to create the storage such as 'mean', '1st quartile', or '3rd quartile' in both the Figure and the results section. - All individual storages calculations (all event and duration simulations) have been extrapolated to all nominal outflow positions prior to the statistical analysis being undertaken. The statistical analysis was then calculated on the extrapolated individual

[2] A larger range of ARI and durations were considered during testing. A comparison found that no notable difference in the establishment of the stream lag factor or the storage calculations with a smaller range of ARI and durations.

Step	Comment
	storages. An example is also shown in Figure 3.2 where the blue dots are the extrapolation of the individual storage curves (from the orange dots) and the dashed lines are the statistical analysis on the extrapolated data (orange and blue dots combined). This method is summarised according to the statistical method used to create the storage with the additional tag of '(extrapolated)' such as 'mean (extrapolated)', '1st quartile (extrapolated)', or '3rd quartile (extrapolated)' in both the Figure and the results section.

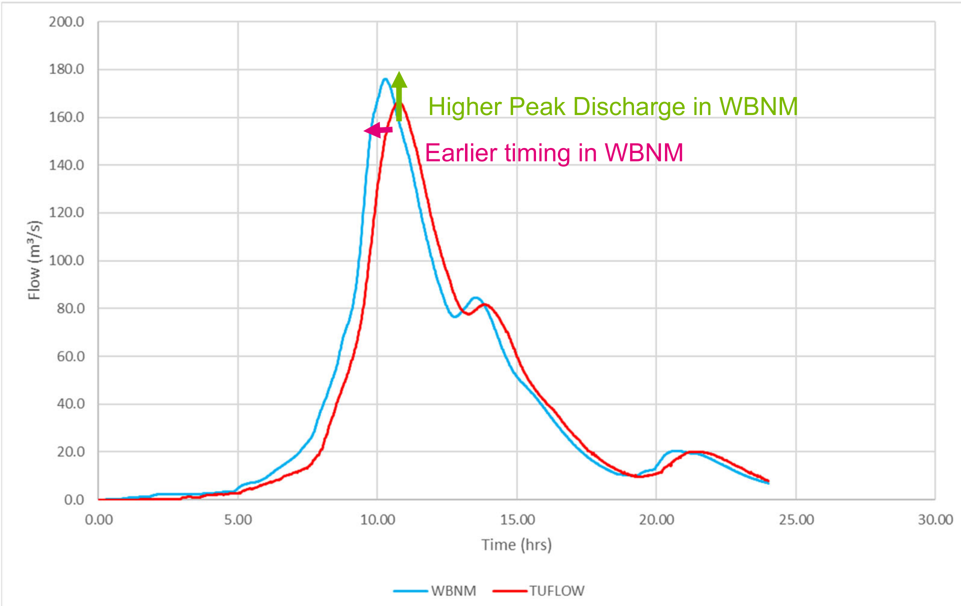


Figure 3.1 Ideal WBNM hydrograph for application of artificial storage

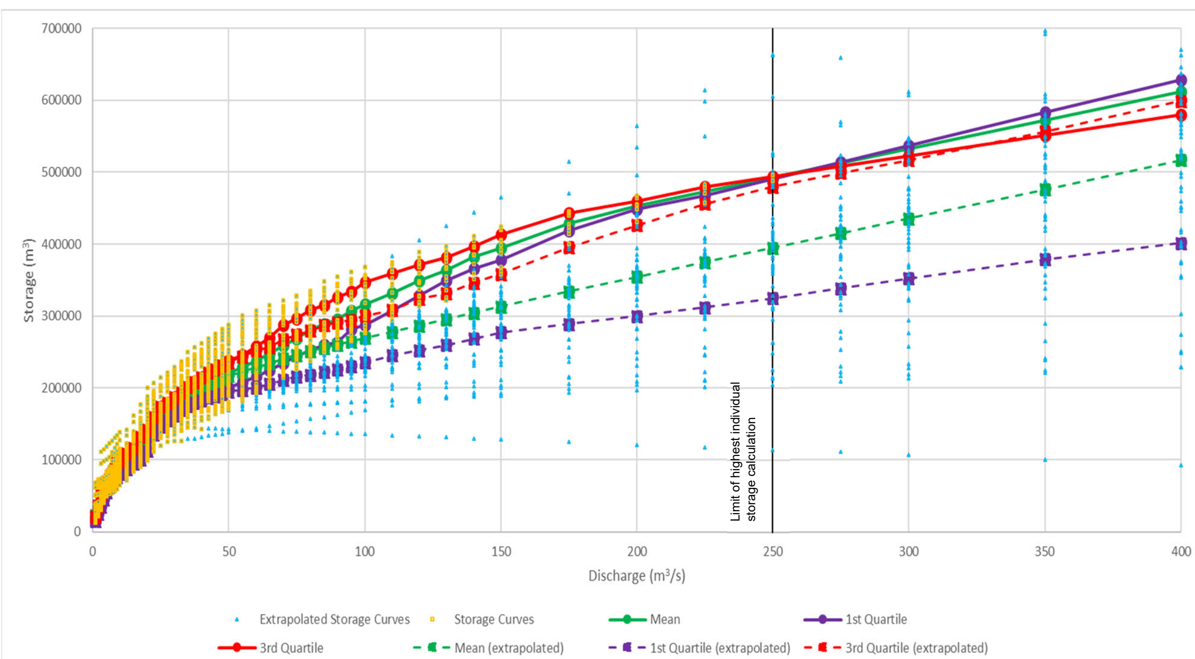


Figure 3.2 Statistical analysis for creating artificial storage curves

3.2 Scoring System for Comparison

A scoring system was implemented to assist with determining the best stream lag factor applied for each HEH area. The system is based on achieving the lowest score using the three criteria stated in HEH methodology stated in the separate Technical Note (i.e. the timing of the peak discharge, the peak ratio, and the Nash-Sutcliffe Efficiency), where a perfect score would be zero points. Points were calculated for every simulation for a given stream lag factor (i.e. all ARI events and all durations for the ARI events). Points are added based on the following:

- The timing of the peak discharge – a point is added for every minute the WBNM simulation is different from the TUFLOW simulation. An exact match in the timing would receive no points, where a difference of ±5 minutes receives 5 points.
- The peak ratio – a point (and faction of a point) is added for the percentage that the peak discharge of the WBNM simulation is different to the TUFLOW simulation. A peak ratio of 0 percent for the simulation would receive no points, where a difference of 5 percent (i.e. the WBNM is 95% or 105% of the TUFLOW discharge) receives 5 points.
- Nash-Sutcliffe efficiency – a point (and faction of a point) is added for every decimal the simulated WBNM Nash-Sutcliffe diverges from 1 (a perfect match). A perfect Nash-Sutcliffe would receive no points, where a Nash-Sutcliffe of 0.95 would receive 5 points.

The component scores from all simulations at a given HEH point are summed, then divided by the number of simulations to give a final score. Noting that a perfect score of zero is practically improbable, a good score was considered to be below 30 (using 15-minute difference in timing, 10% peak ratio, 0.95 Nash-Sutcliffe efficiency) and an excellent score was considered to be below 18 (using 10-minute difference in timing, 5% peak ration, 0.97 Nash-Sutcliffe efficiency).

4 WBNM HEH model

The final WBNM model stream lag factors, HEH points with applied artificial storage, and final score for each HEH point within the SID catchment are summarised in Table 4.1. The scores are colour coded according to the degree to which they achieve the desired match, where green represents an excellent score, dark blue a good score, and red a score outside the desired criteria. A map of the stream lag factors and artificial storage locations is shown in Figure 4.1.

In addition, the average and the worst results for the three criteria are summarised in Table 4.2. Each value within the Table is coloured light blue if the within the required criteria. The worst results have been displayed to give an indication of the outer bounds of the results used to derive the average. The average and worst peak ratio and difference in timing presented in the Table have been calculated using absolute values, hence positive and negative values are not cancelling each other (i.e. an average of two scores of -10 and +10 equals zero). Accompanying this memo, BMT has supplied excel spreadsheets of the criteria performance across all simulated ARI events and durations at all HEH points (file named “Statistics.csv”).

BMT has supplied a digital package of the final individual hydrograph comparisons for all ARI events and duration at every HEH point. For ease of viewing, an html file has been provided whereby the user can either select individual plots, jump between HEH points whilst viewing all ARI events and duration for that point, or view all plots for all HEH points simultaneously (file named “_hydro_overview_SID.html”). Figure 4.2, Figure 4.3, Figure 4.4, and Figure 4.5 present examples of the comparisons at HEH point ‘SID001_17789’ for the 5-year, 20-year, 100-year, and 2000-year ARI respectively. Each plot shows the final WBNM hydrograph in blue, and the TUFLOW hydrograph in red. Plots also include the time that the peak occurs and the peak discharge in m^3/s for both the WBNM and TUFLOW hydrographs. These labels are presented in their respective colour in the following format “hh:mm:ss : xx.xx” (an example is “12:35:00 : 156.04”). A table of three criteria for HEH point ‘SID001_17789’ is also summarised in Table 4.3 for all modelled ARI events and durations.

When reviewing the supplied digital results, the following should be noted:

- For HEH points where artificial storage was introduced, the WBNM hydrograph is the outlet discharge from the storage.
- At confluences, the WBNM hydrograph is the combination of the upstream catchments (where a common sub-catchment combining tributary discharge is not present).
- At culverts, the TUFLOW hydrograph is a combination of TUFLOW’s plot outlet (“PO”) and 1D results (“1d_Q”) i.e. all flow passing either through, or bypassing the culvert is captured.

From reviewing the results for the SID catchment, the following can be stated:

- All HEH points, have final scores that are considered either ‘good’ or ‘excellent’ with most of the HEH scores considered ‘excellent’. The average of all three criteria at all HEH points, except the difference in timing at ‘SID001_01506’, is within the desired tolerance, with most points outperforming the desired tolerance. The difference in timing at ‘SID001_01506’ (outlet of Lake Kurwongbah) is considered acceptable is it is a large waterbody.
- Two storages were applied in Lake Kurwongbah, one at the inlet from Browns Creek (the combined flow of SID001_06735 and SID003_00000) and the other at the downstream of the model (SID001_01506).

- A dummy sub-catchment 'SID001_06DUM' have been included to implement an artificial storage. No dummy sub-catchments were required at confluences for the 'design event modelling' points.
- In general, the stream lag factors are lower at the top of the catchment and become larger downstream. Only within the waterbody of Lake Kurowongbah does the stream lag factor decrease. It would be expected that the flood wave would travel faster than in normal reaches within this waterbody.

Overall, it is considered that the HEH model is suitable for use in ARR2019 design event selection.

Table 4.1 Adopted Stream Lag Factor, Artificial Storage Information, and Final Score

HEH Point Name	Adopted Stream Lag Factor	Artificial Storage Included	Artificial Storage Calculation Method	Final Score (Score without Artificial Storage)
SID010_01949	0.70			19.7
SID004_06165	0.40			9.9
SID004_00814	0.80	✓	Mean (extrapolated)	12.6 (57.7)
SID001_17789	0.40			11.2
SID001_15769	0.65			14.7
SID001_11334	0.60	✓	Mean (extrapolated)	16.1 (117.2)
SID001_10382	1.20			11.0
SID001_09197	1.20			11.0
SID001_08305	1.20			11.6
SID001_01506	0.25	✓	Mean	26.5[1,2] (918.6)

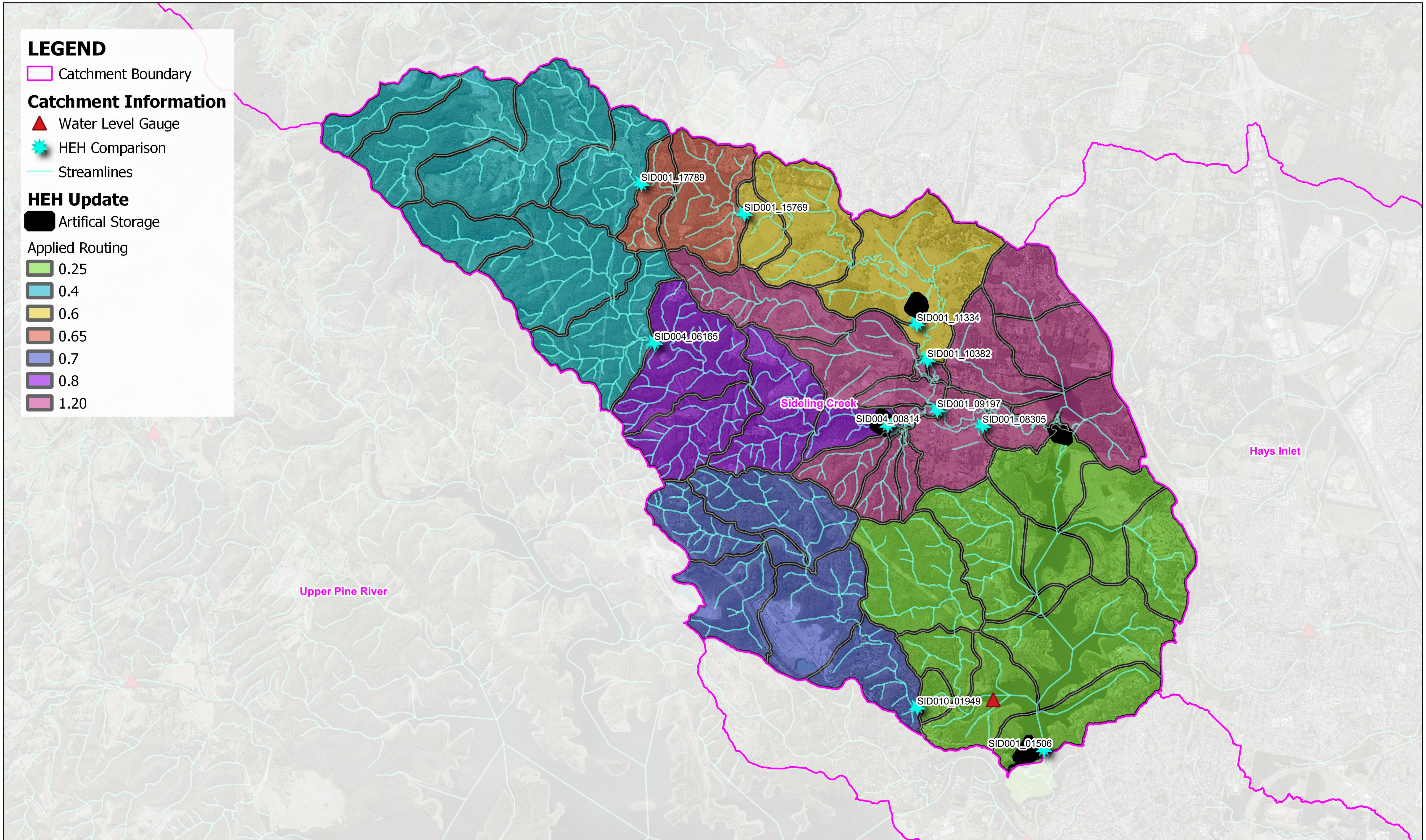
1 A stream lag factor of 0.25 was used within the dam, whilst a stream lag factor of 1.2 was used to the inlet to Lake Kurowongbah (SID001_06735 and SID003_00000). Higher stream lag factors across the dam were applied with limited success of matching the hydrograph at the model outlet.

2 Two storages were applied, the first at SID001_06735 which had a final score of 11.7 using a 'Mean (extrapolated)' artificial storage calculation.

Table 4.2 Average and Worst Criteria for all ARI Events and Duration for the Adopted Stream Lag Factors and Artificial Storages

HEH Point Name	Average (Lowest) Nash-Sutcliffe Efficiency	Average (Largest) Peak Ratio (%)	Average (Largest) Difference in Timing (minutes)
SID010_01949	0.95 (0.90)	7.5 (12.3)	7.1 (15.0)
SID004_06165	0.99 (0.98)	3.3 (6.7)	5.4 (15.0)
SID004_00814	0.98 (0.95)	3.5 (13.5)	7.1 (15.0)
SID001_17789	0.98 (0.96)	4.2 (8.2)	5.4 (10.0)
SID001_15769	0.98 (0.96)	5.8 (12.8)	7.1 (25.0)
SID001_11334	0.95 (0.87)	2.5 (6.0)	8.3 (15.0)
SID001_10382	0.97 (0.93)	2.8 (7.7)	5.0 (15.0)
SID001_09197	0.99 (0.97)	2.9 (7.6)	6.7 (15.0)
SID001_08305	0.99 (0.96)	5.0 (9.0)	5.0 (10.0)

HEH Point Name	Average (Lowest) Nash-Sutcliffe Efficiency	Average (Largest) Peak Ratio (%)	Average (Largest) Difference in Timing (minutes)
SID001_01506	0.97 (0.95)	8.1 (12.3)	15.4 (20.0)



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Applied Routing and Artifical Storage

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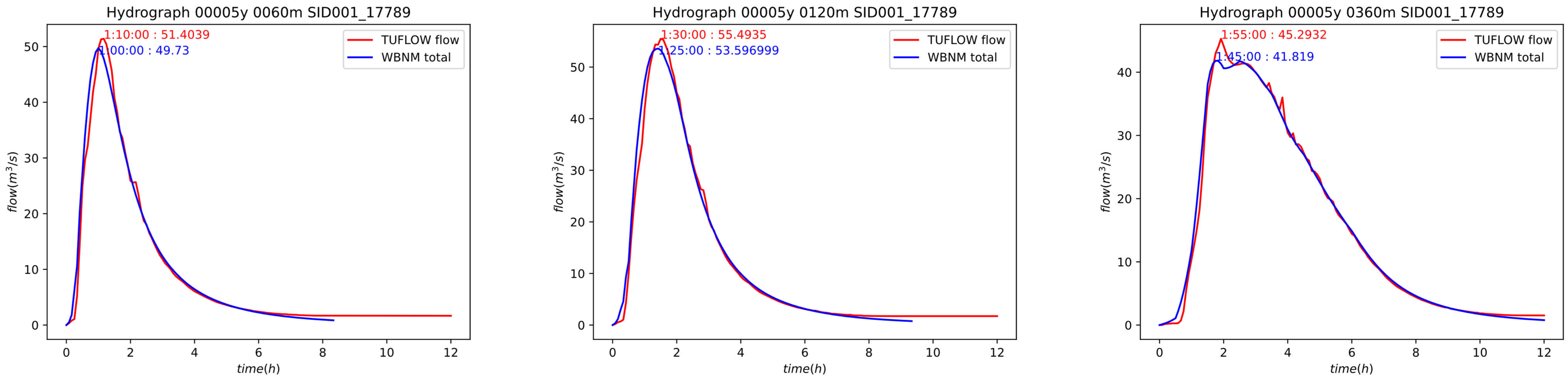


Figure 4.2 SID001_17789 for the 5-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

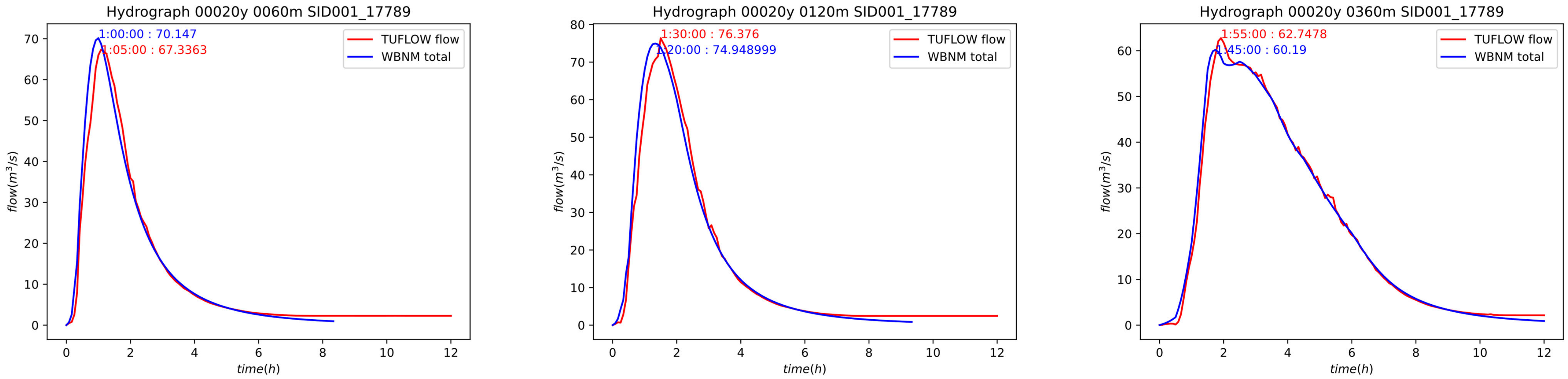


Figure 4.3 SID001_17789 for the 20-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

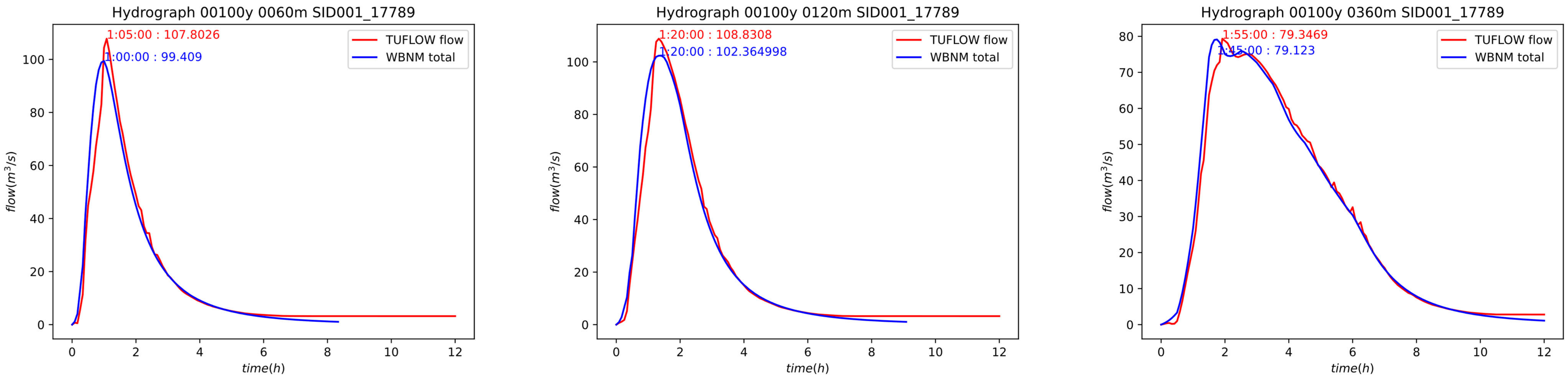


Figure 4.4 SID001_17789 for the 100-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

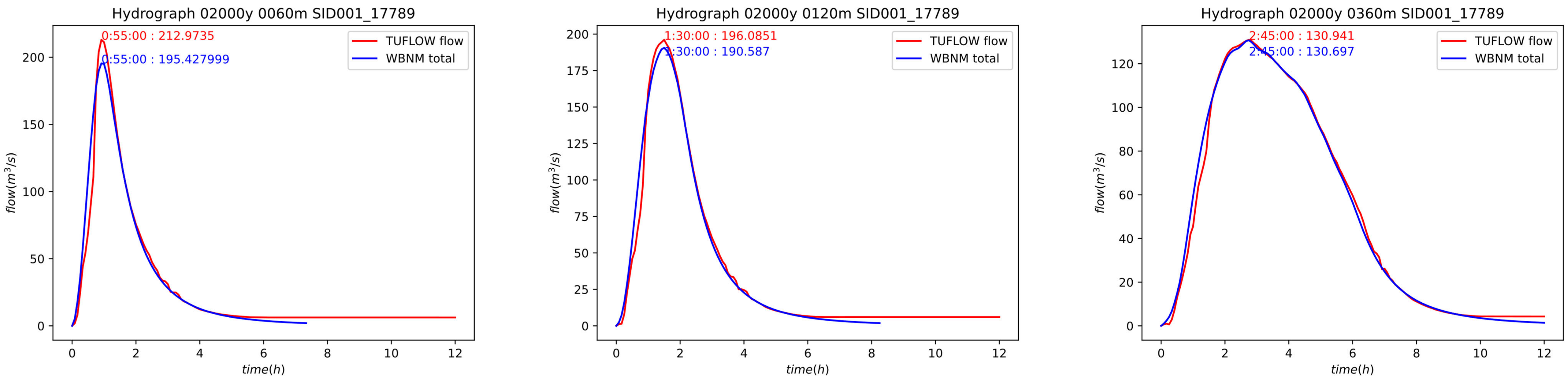
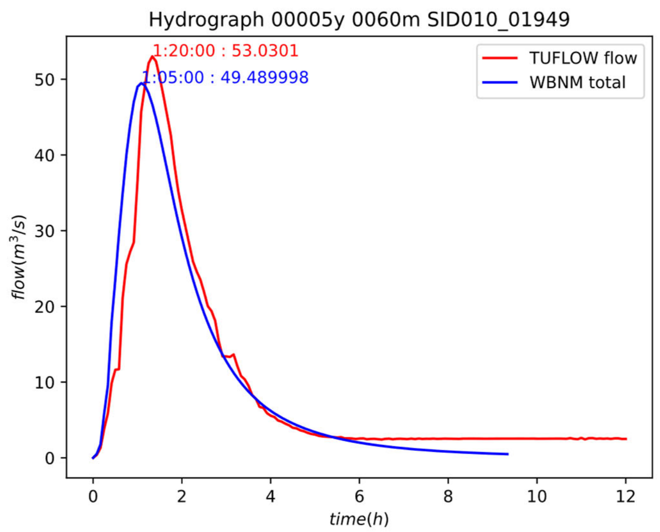


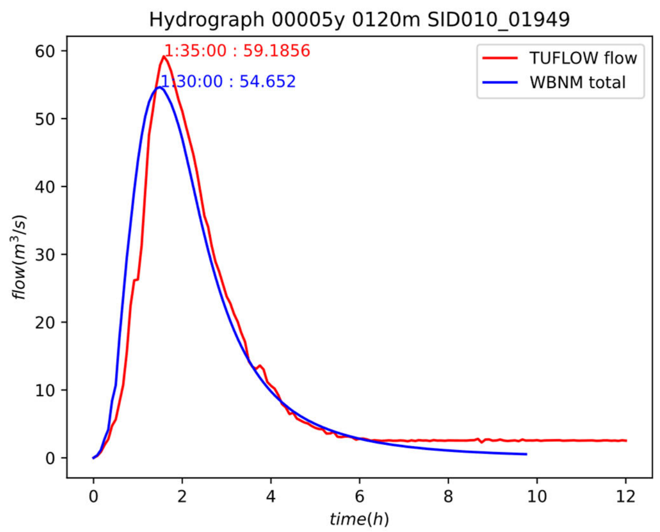
Figure 4.5 SID001_17789 for the 2000-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

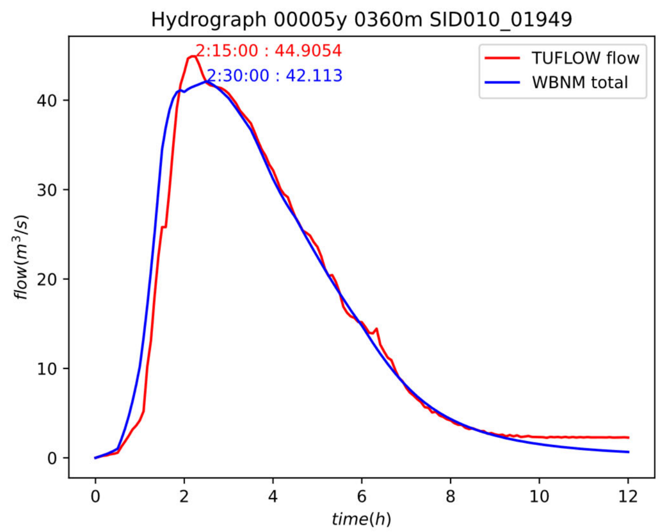
Table 4.3 Criteria for all ARI Events and Duration for SID001_17789

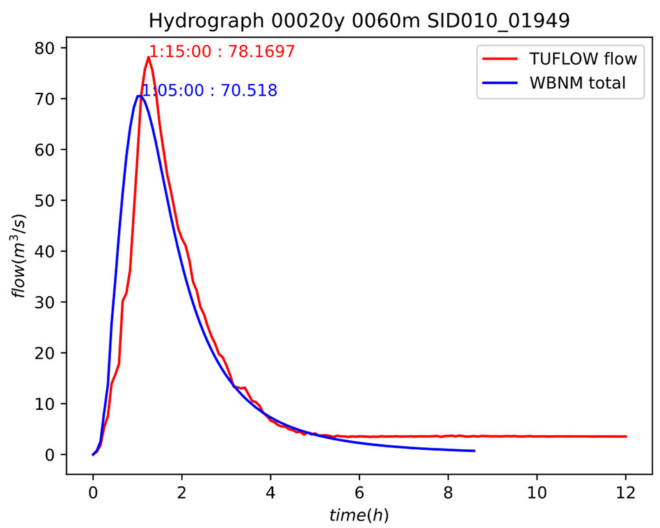
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.99	-3.3	-10.0
5-year 120-minute	0.99	-3.4	-5.0
5-year 360-minute	0.99	-7.7	-10.0
20-year 60-minute	0.98	4.2	-5.0
20-year 120-minute	0.98	-1.9	-10.0
20-year 360-minute	0.99	-4.1	-10.0
100-year 60-minute	0.96	-7.8	-5.0
100-year 120-minute	0.98	-5.9	0.0
100-year 360-minute	0.99	-0.3	-10.0
2000-year 60-minute	0.97	-8.2	0.0
2000-year 120-minute	0.99	-2.8	0.0
2000-year 360-minute	1.00	-0.2	0.0

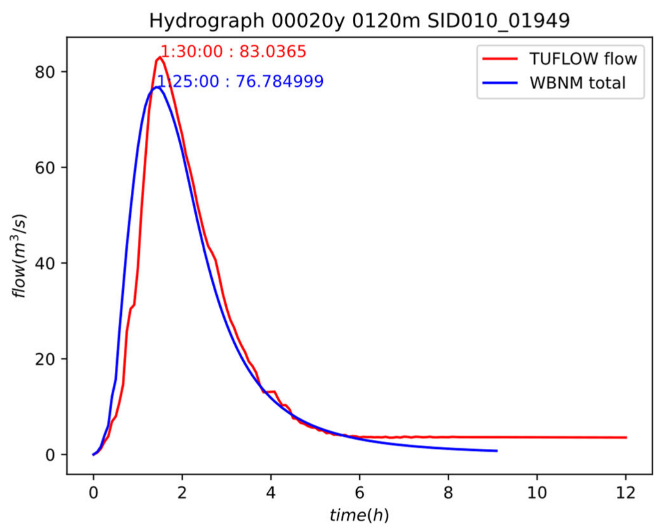
Annex D Sideling Creek HEH Hydrographs

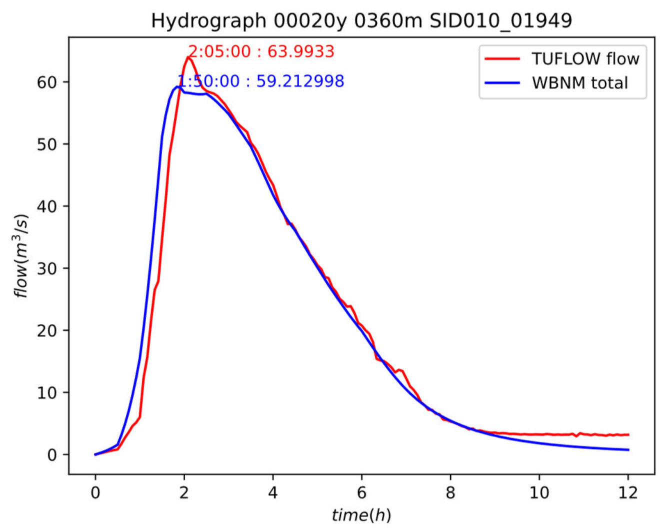




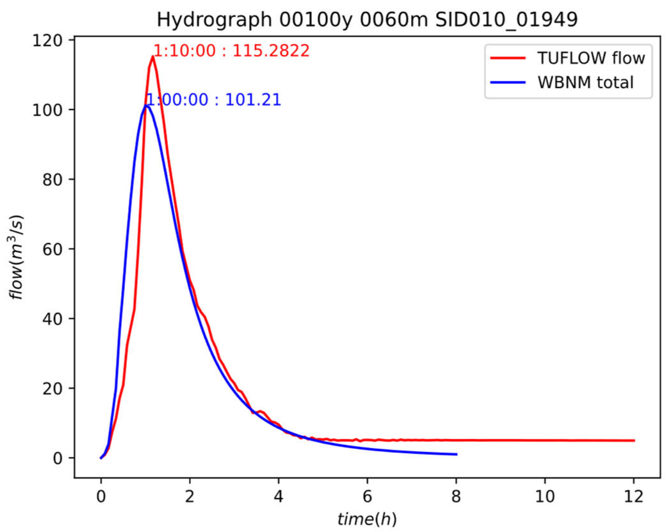


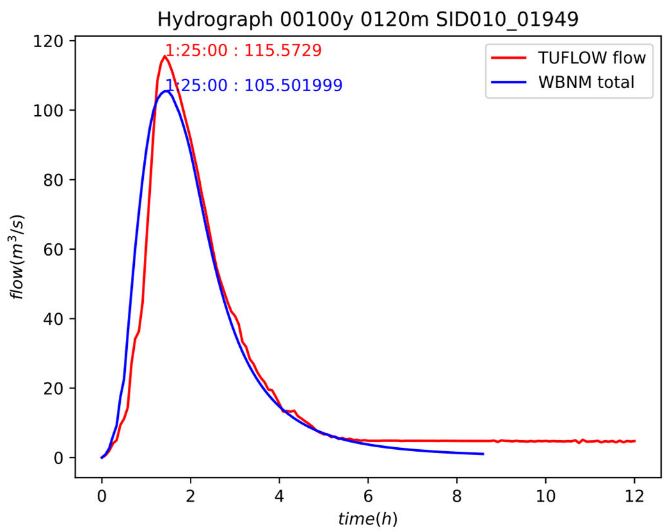


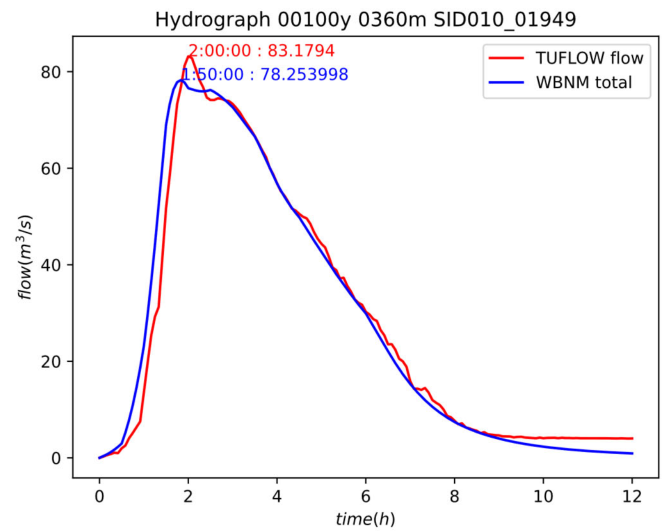


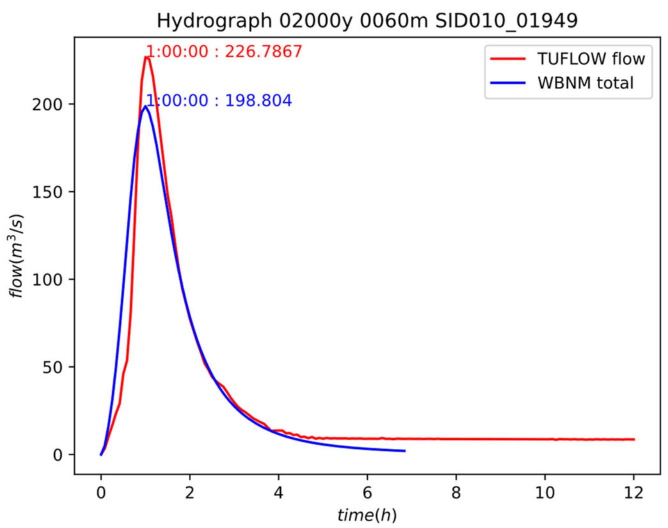


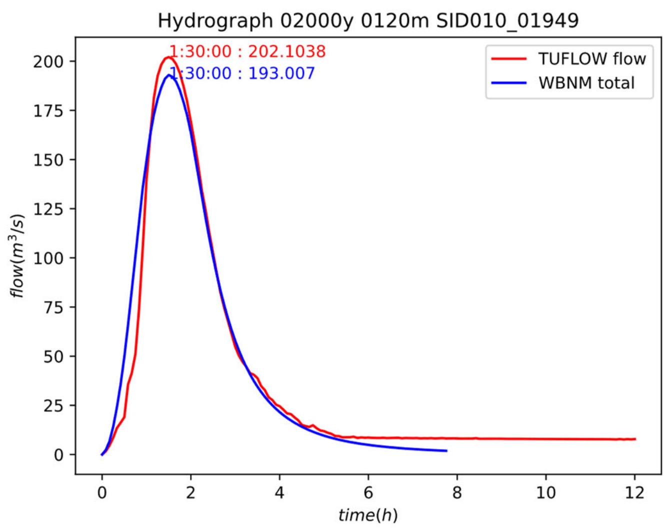
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.91	-6.7	-15
5-year 120-minute	0.95	-7.7	-5
5-year 360-minute	0.97	-6.2	15
20-year 60-minute	0.90	-9.8	-10
20-year 120-minute	0.94	-7.5	-5
20-year 360-minute	0.97	-7.5	-15

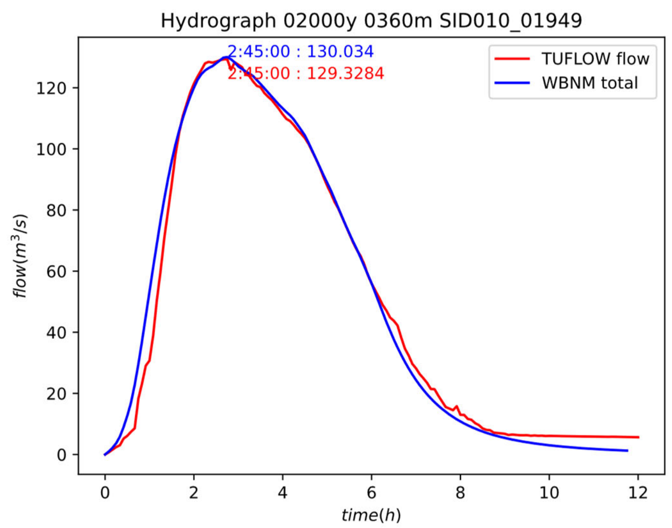




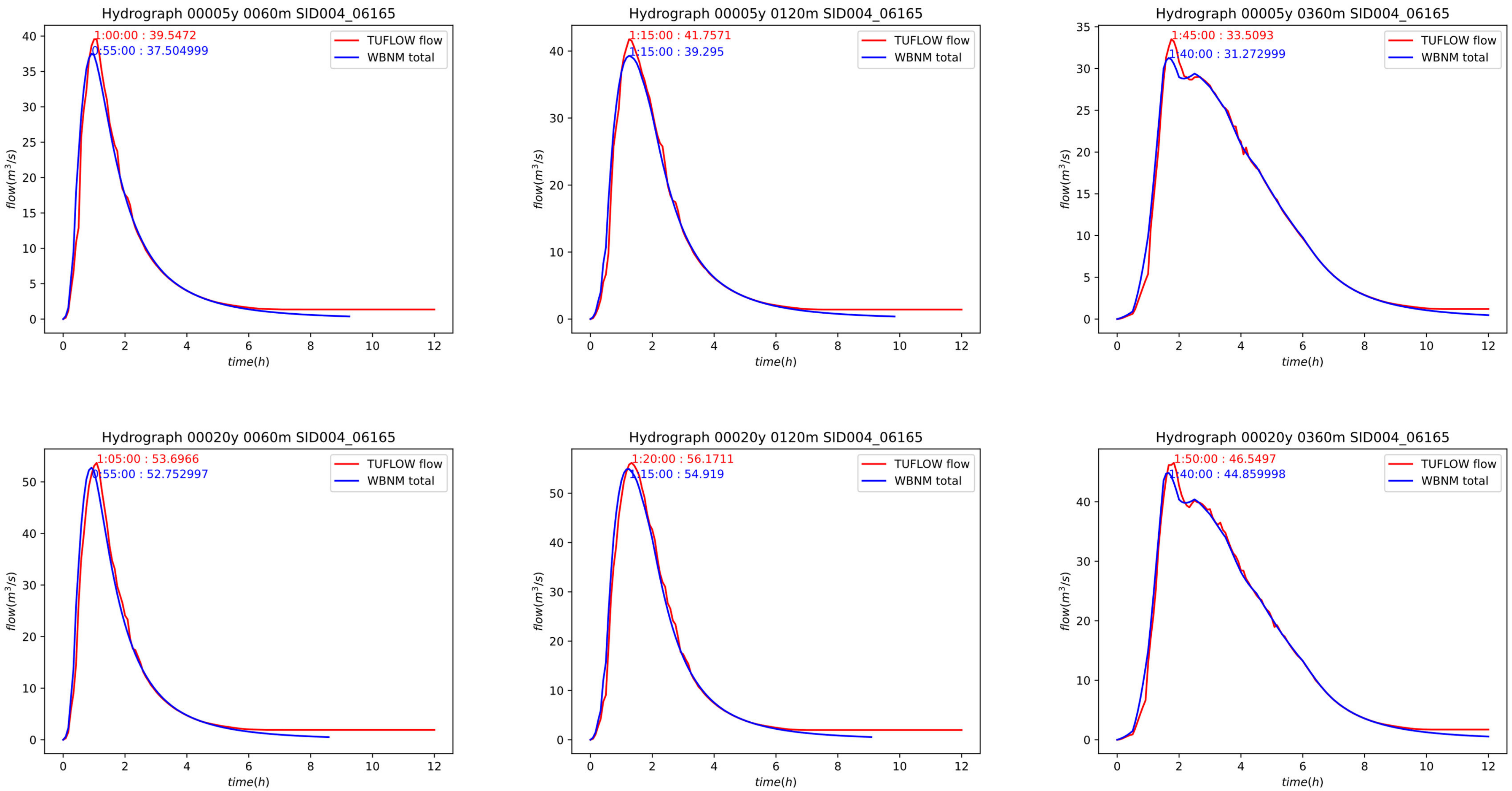




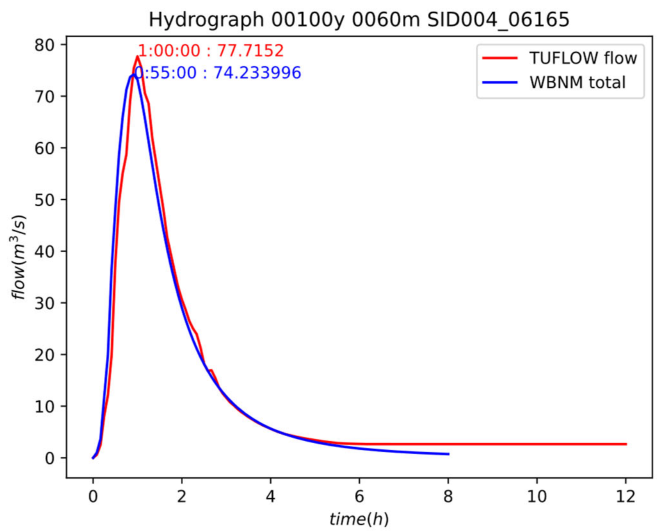


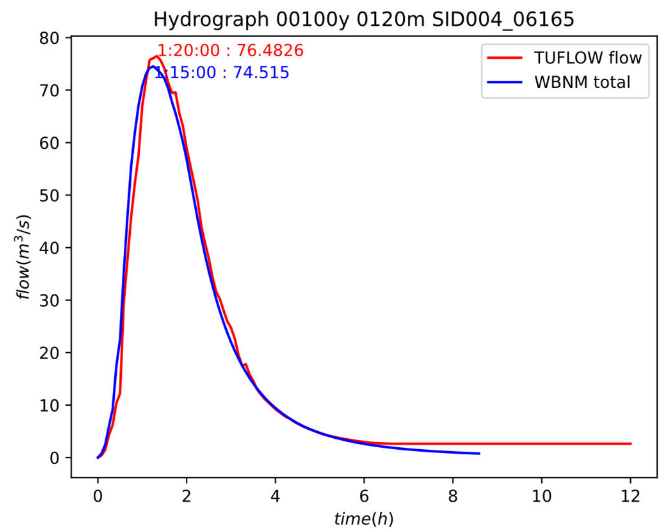


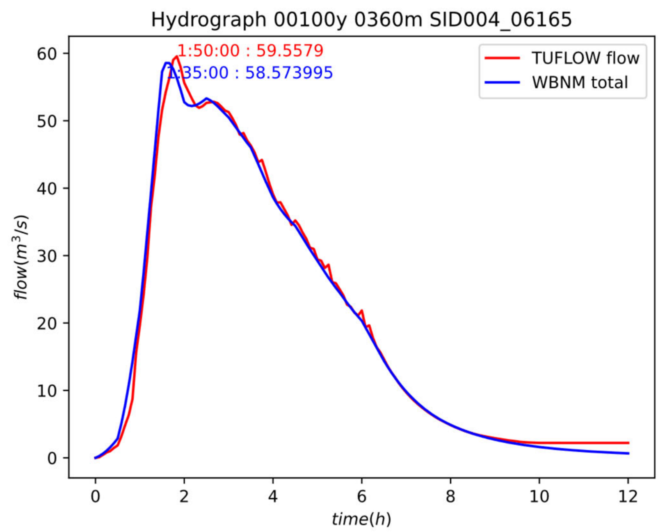
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.91	-12.2	-10
100-year 120-minute	0.95	-8.7	0
100-year 360-minute	0.97	-5.9	-10
2000-year 60-minute	0.94	-12.3	0
2000-year 120-minute	0.97	-4.5	0
2000-year 360-minute	0.99	0.5	0

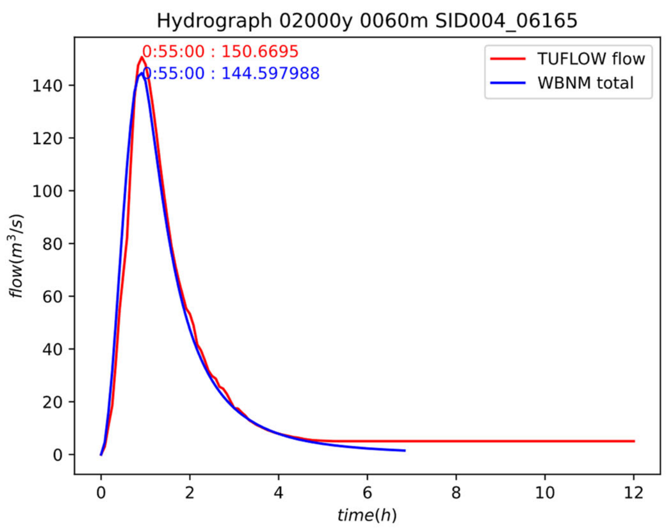


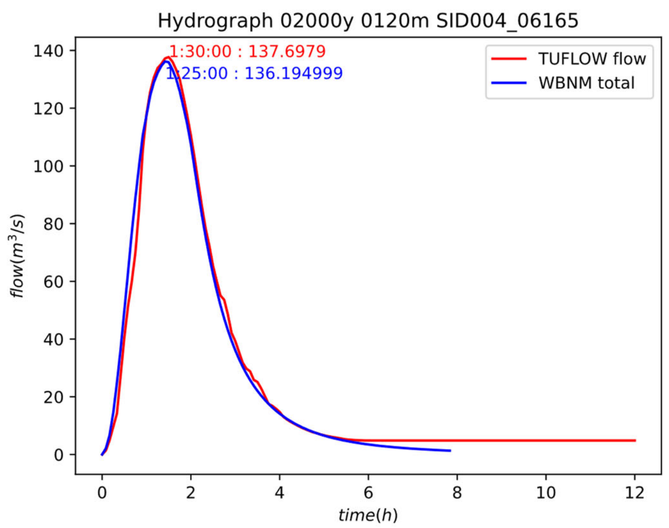
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.98	-5.2	-5
5-year 120-minute	0.99	-5.9	0
5-year 360-minute	0.99	-6.7	-5
20-year 60-minute	0.98	-1.8	-10
20-year 120-minute	0.99	-2.2	-5
20-year 360-minute	0.99	-3.6	-10

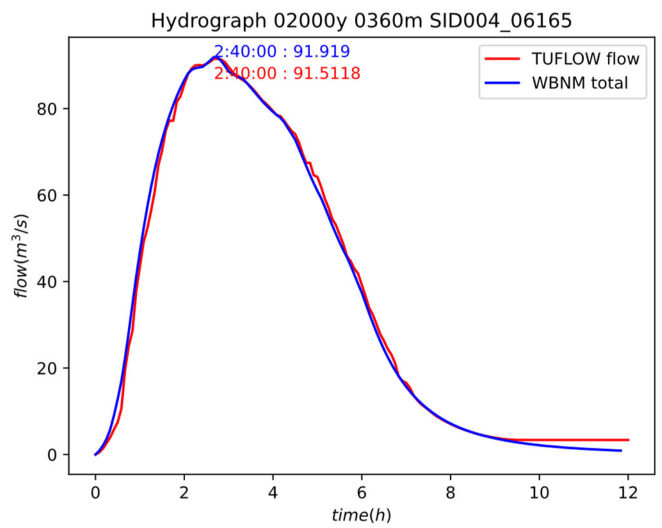




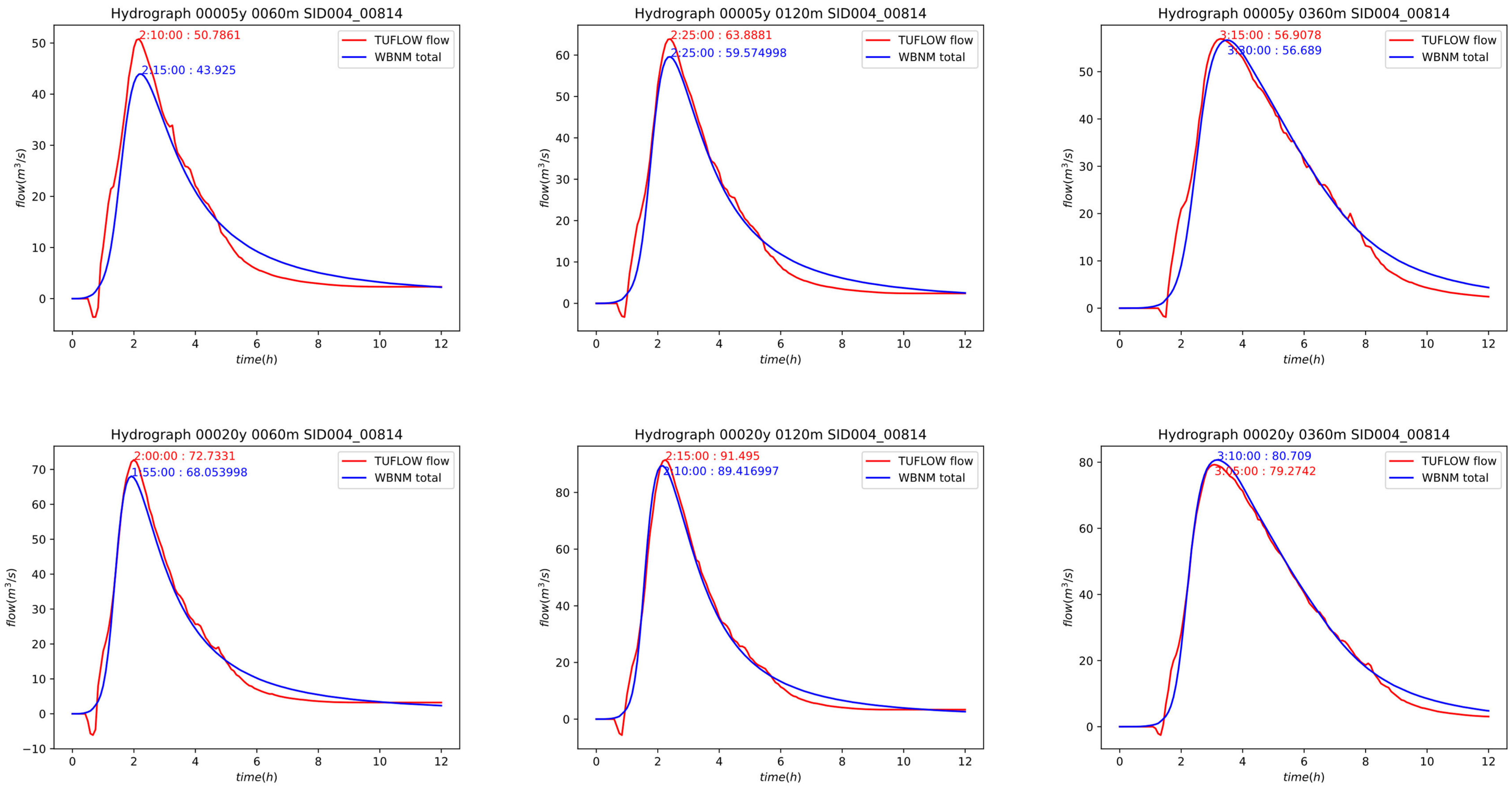




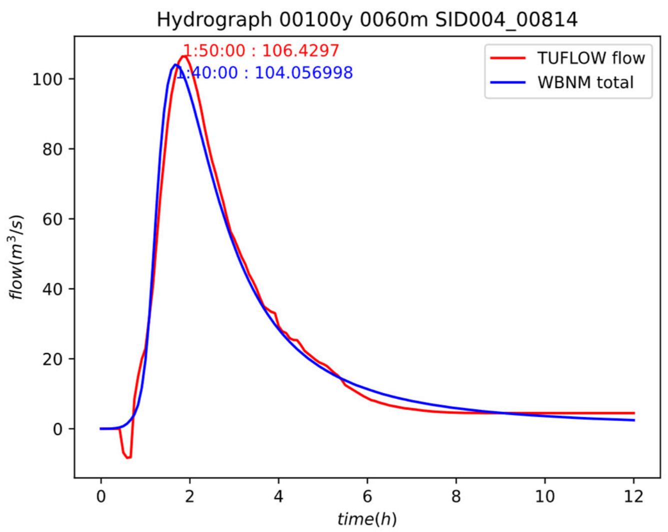


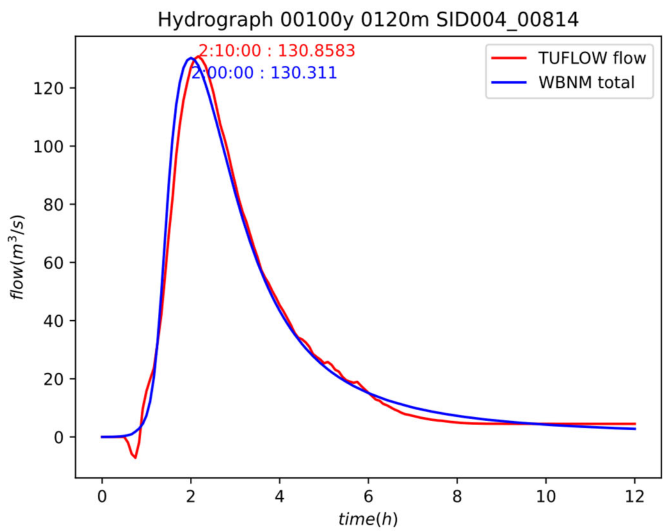


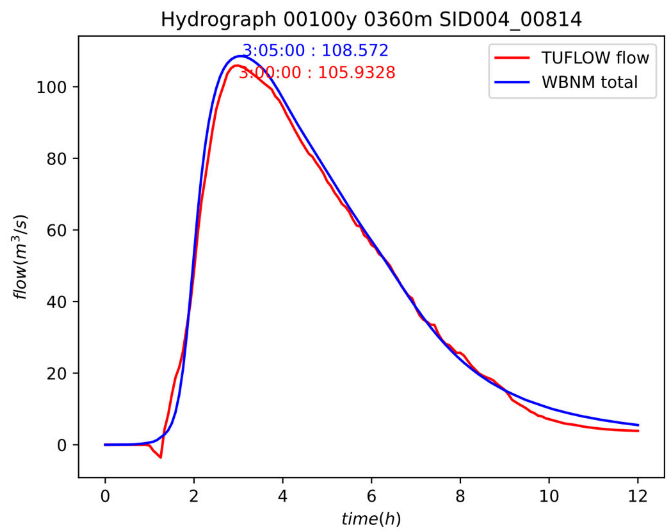
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.98	-4.5	-5
100-year 120-minute	0.99	-2.6	-5
100-year 360-minute	0.99	-1.7	-15
2000-year 60-minute	0.98	-4	0
2000-year 120-minute	0.99	-1.1	-5
2000-year 360-minute	1.00	0.4	0

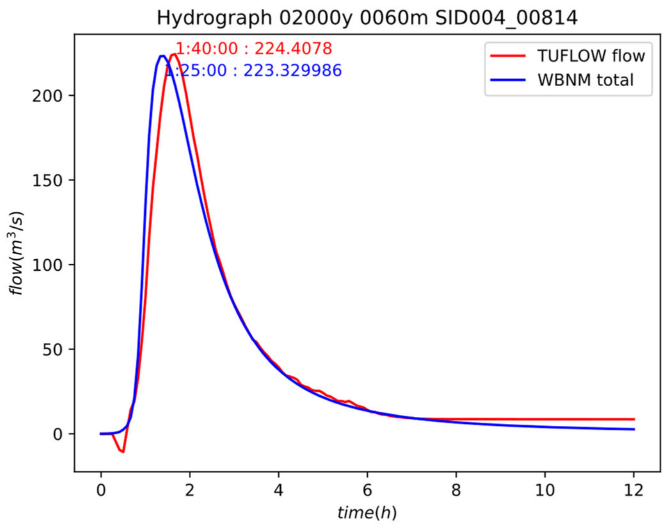


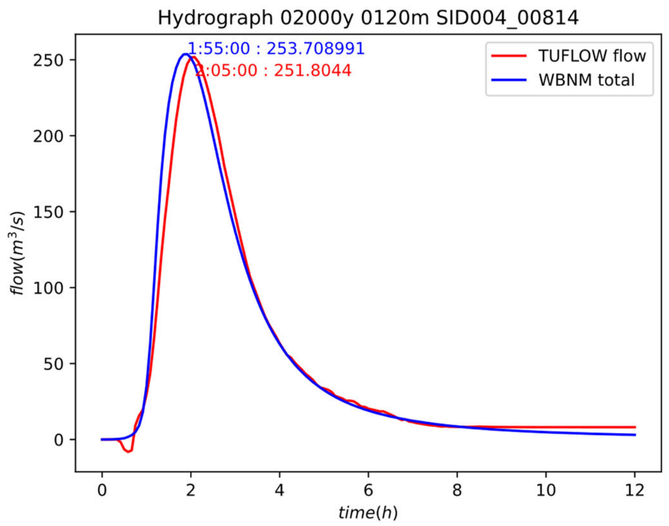
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.95	-13.5	5
5-year 120-minute	0.98	-6.8	0
5-year 360-minute	0.98	-0.4	15
20-year 60-minute	0.98	-6.4	-5
20-year 120-minute	0.99	-2.3	-5
20-year 360-minute	0.99	1.8	5

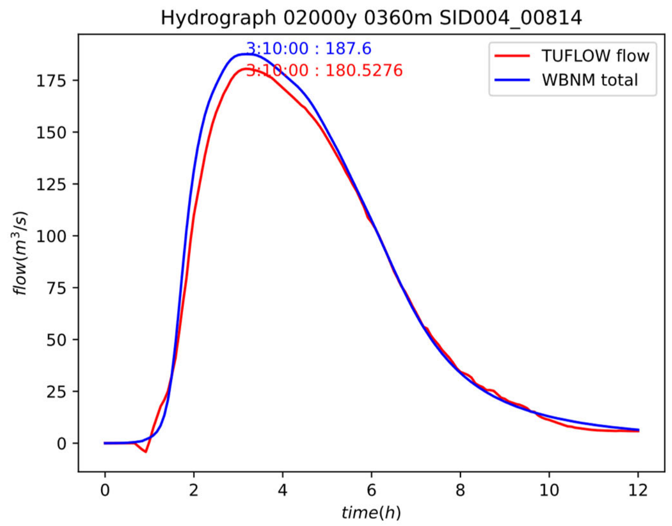




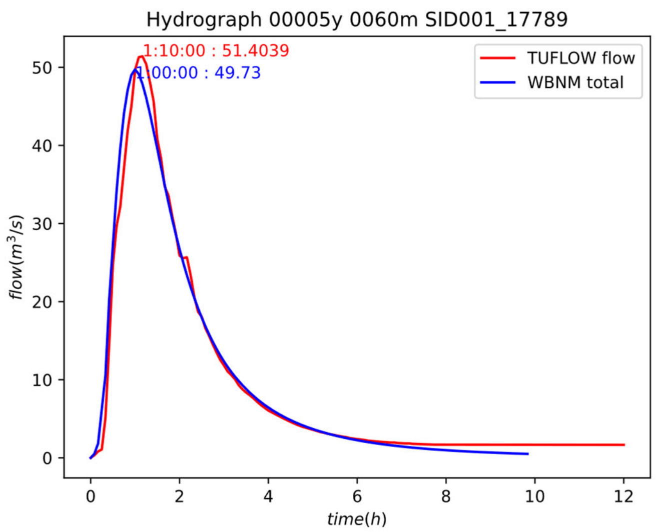


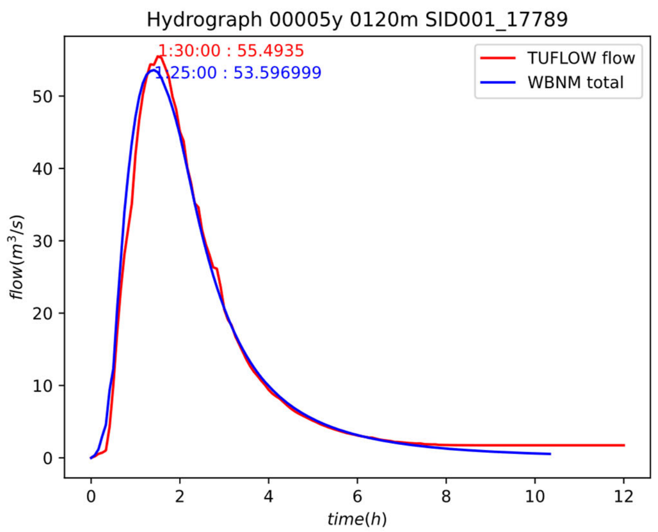


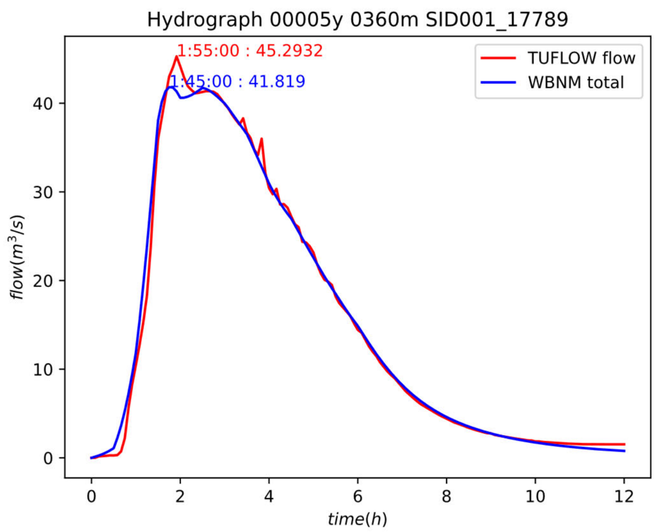


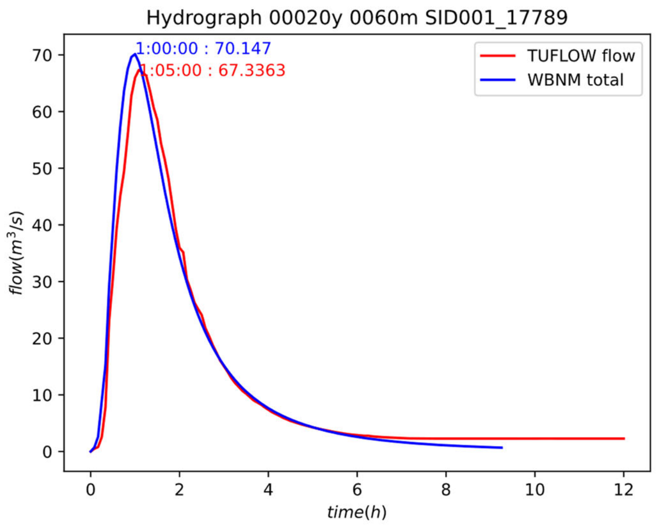


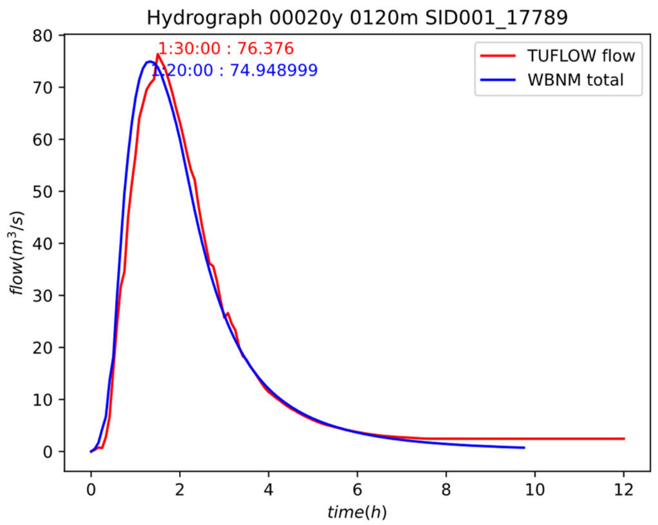
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.98	-2.2	-10
100-year 120-minute	0.99	-0.4	-10
100-year 360-minute	0.99	2.5	5
2000-year 60-minute	0.96	-0.5	-15
2000-year 120-minute	0.97	0.8	-10
2000-year 360-minute	0.99	3.9	0

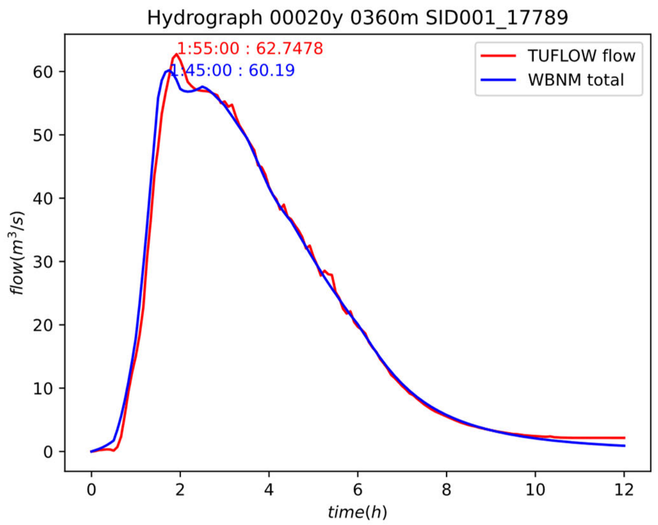




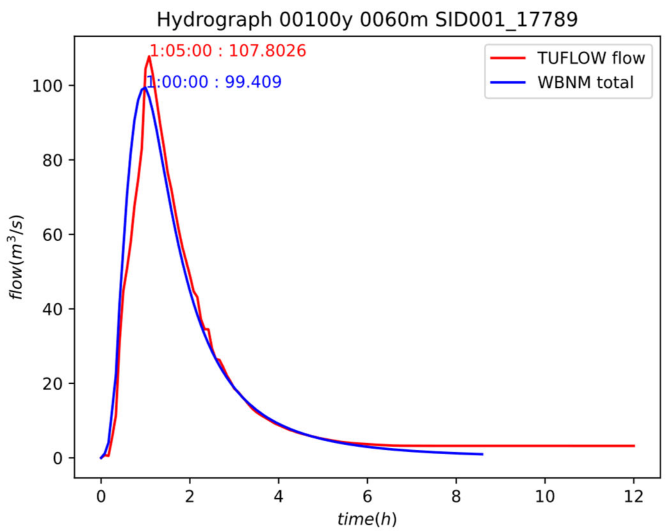


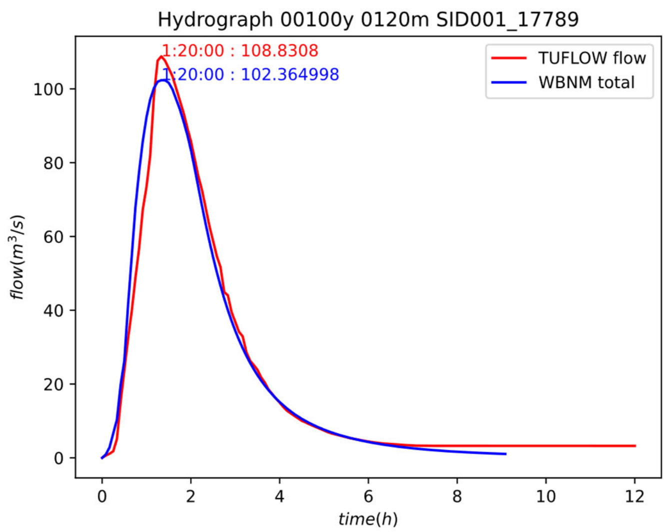


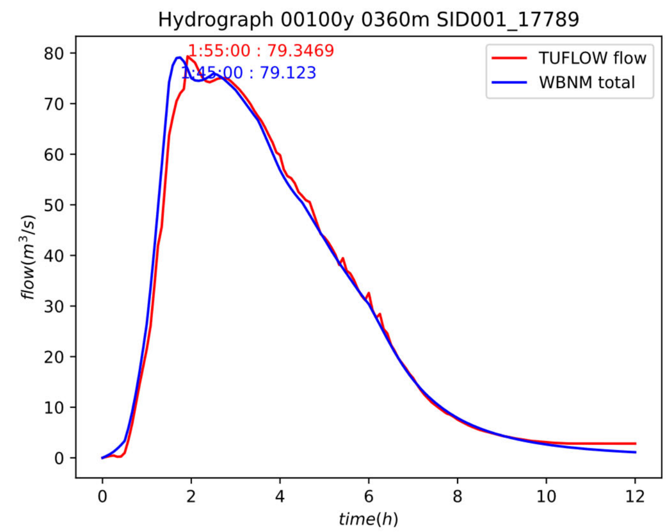


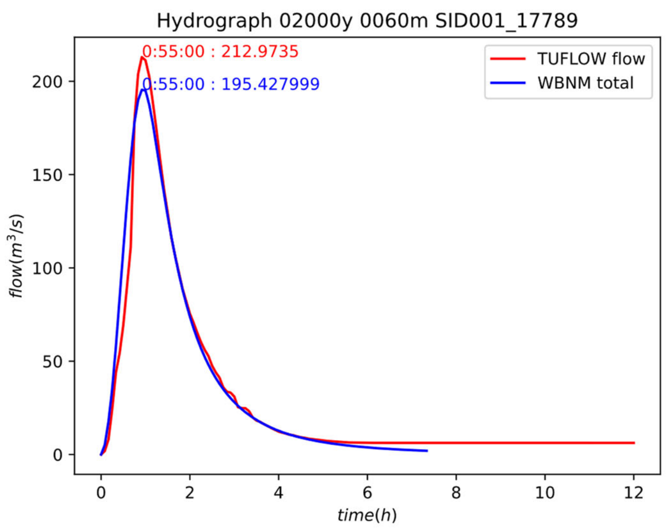


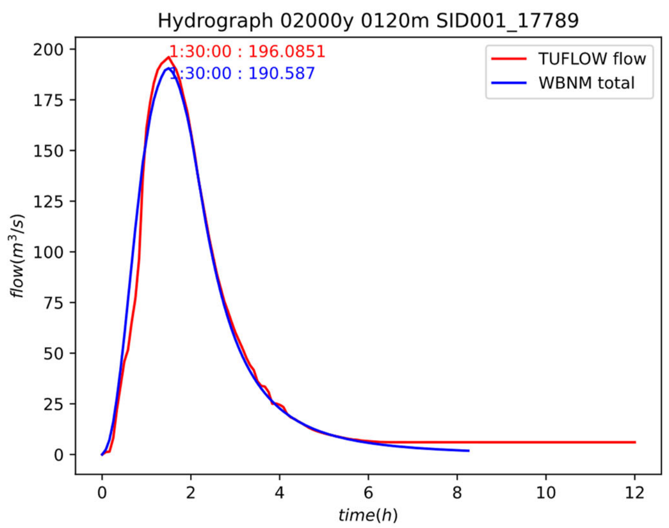
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.98	-3.3	-10
5-year 120-minute	0.99	-3.4	-5
5-year 360-minute	0.99	-7.7	-10
20-year 60-minute	0.98	4.2	-5
20-year 120-minute	0.98	-1.9	-10
20-year 360-minute	0.99	-4.1	-10

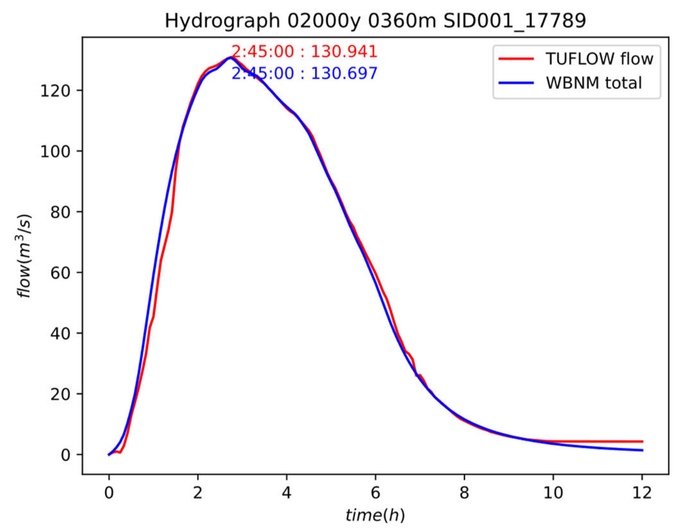




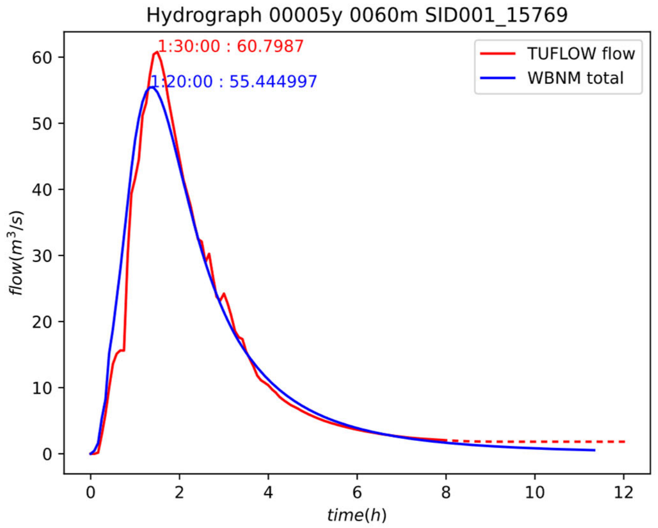


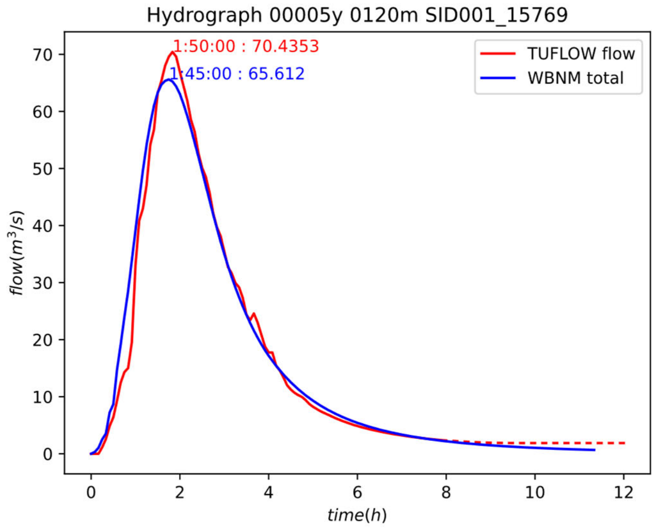


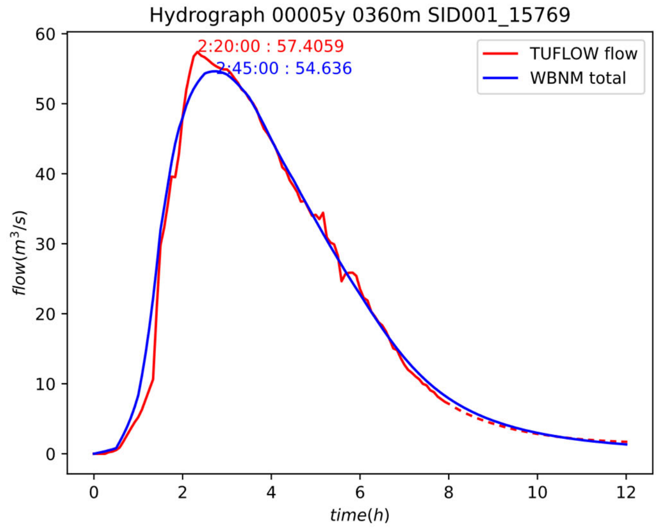


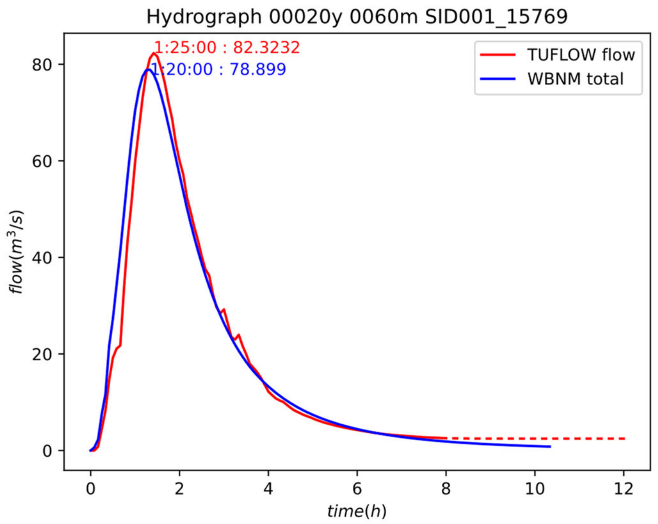


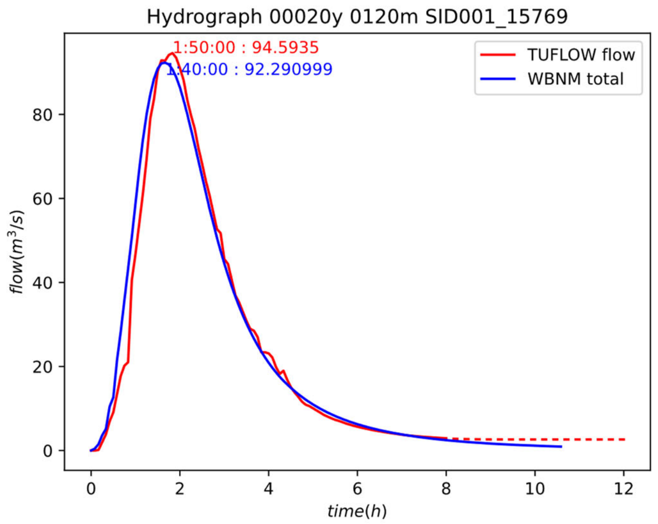
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.96	-7.8	-5
100-year 120-minute	0.98	-5.9	0
100-year 360-minute	0.99	-0.3	-10
2000-year 60-minute	0.97	-8.2	0
2000-year 120-minute	0.99	-2.8	0
2000-year 360-minute	1.00	-0.2	0

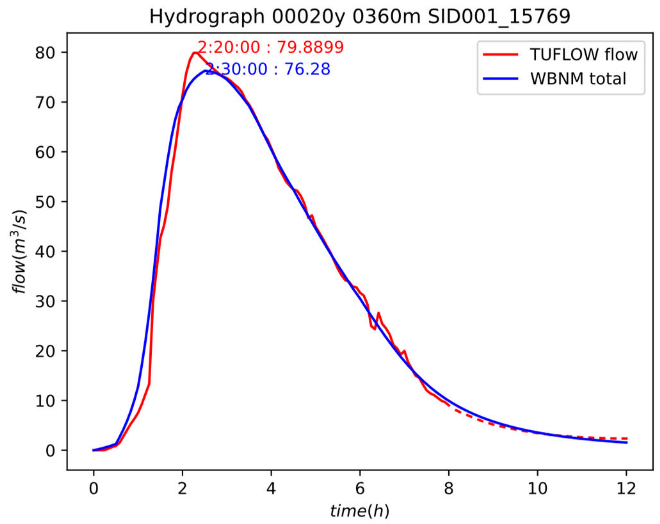




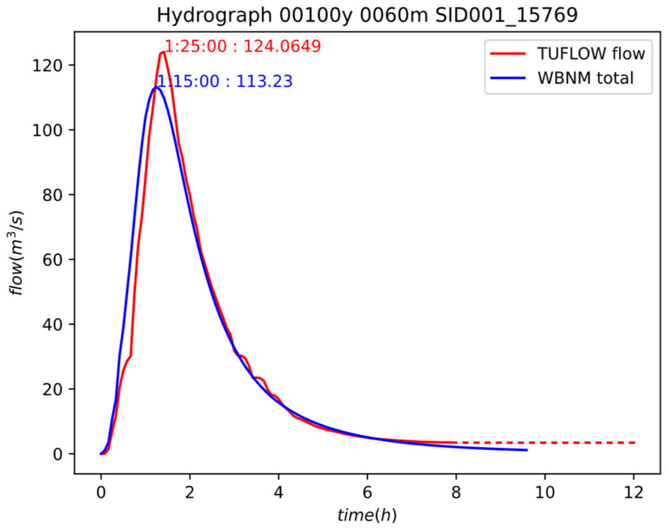


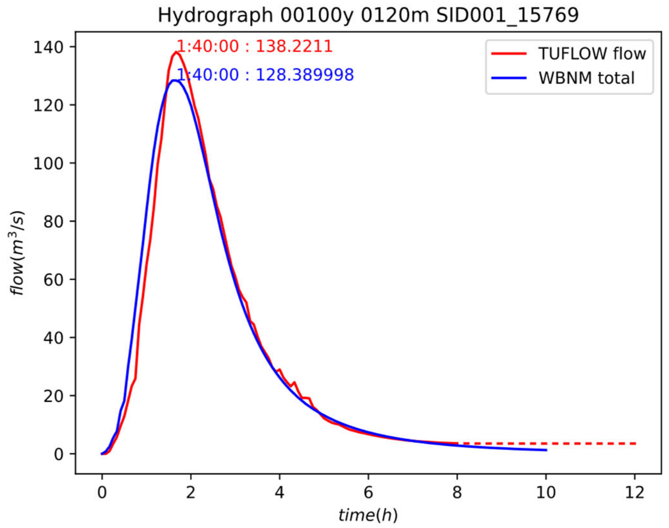


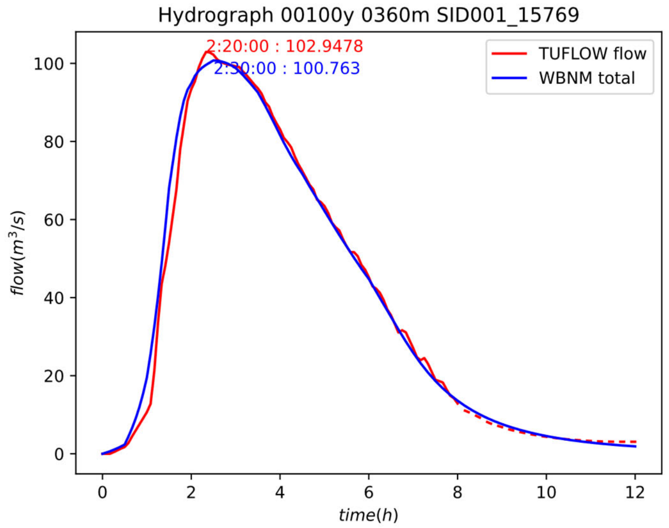


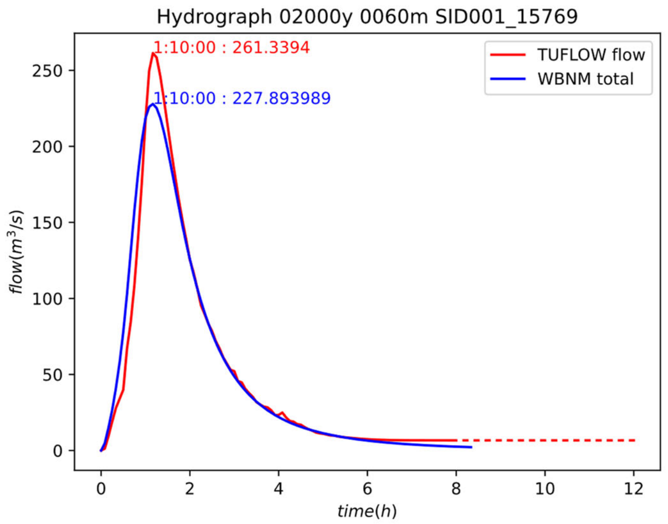


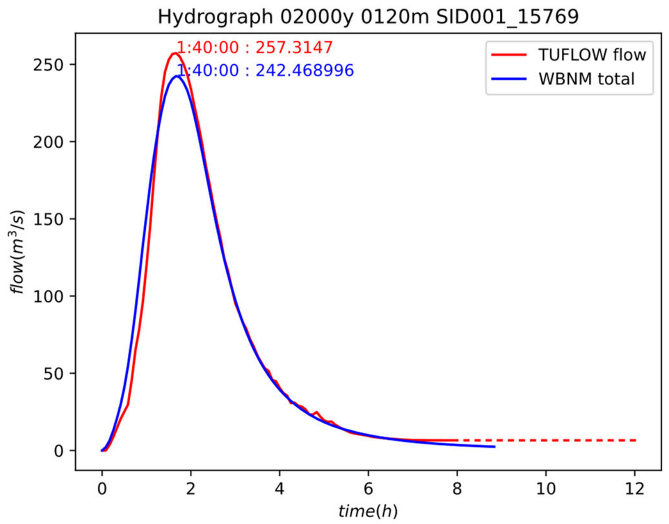
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.97	-8.8	-10
5-year 120-minute	0.98	-6.8	-5
5-year 360-minute	0.99	-4.8	25
20-year 60-minute	0.97	-4.2	-5
20-year 120-minute	0.98	-2.4	-10
20-year 360-minute	0.99	-4.5	10

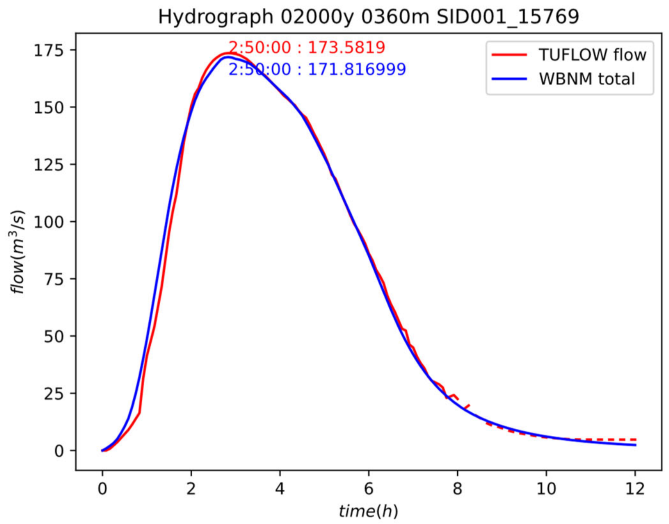




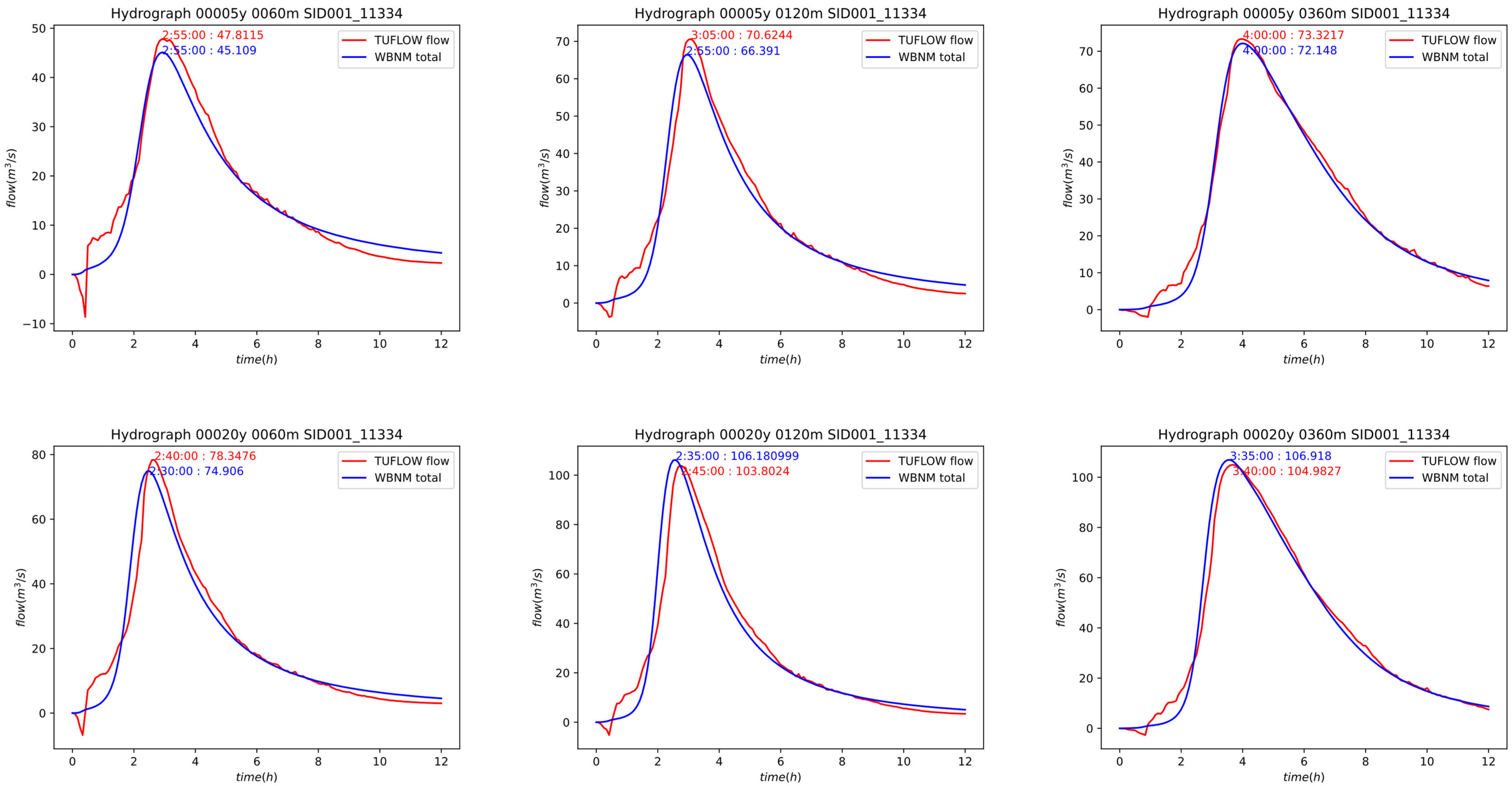




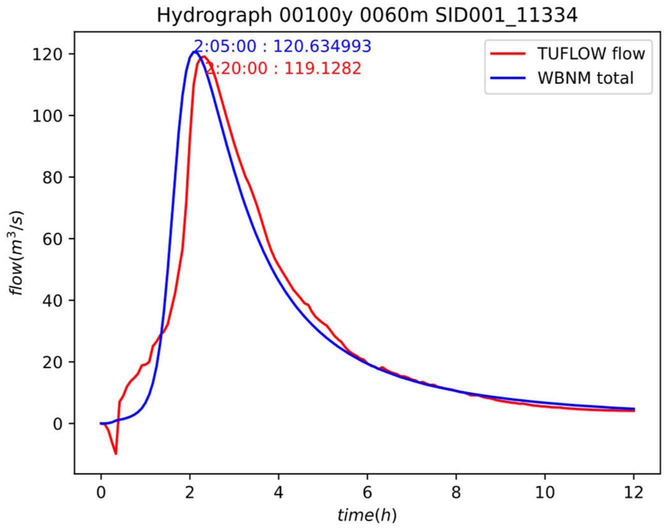


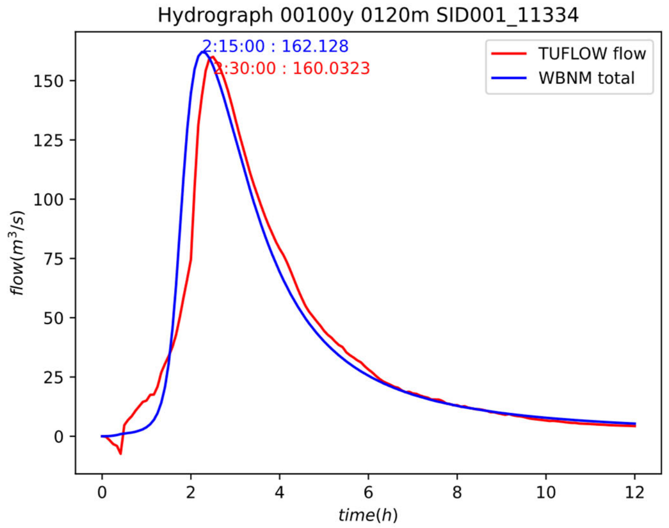


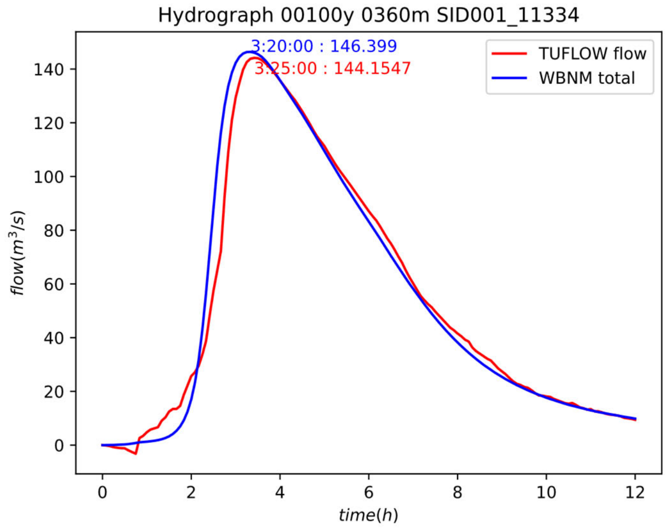
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.96	-8.7	-10
100-year 120-minute	0.98	-7.1	0
100-year 360-minute	0.99	-2.1	10
2000-year 60-minute	0.97	-12.8	0
2000-year 120-minute	0.99	-5.8	0
2000-year 360-minute	1.00	-1	0

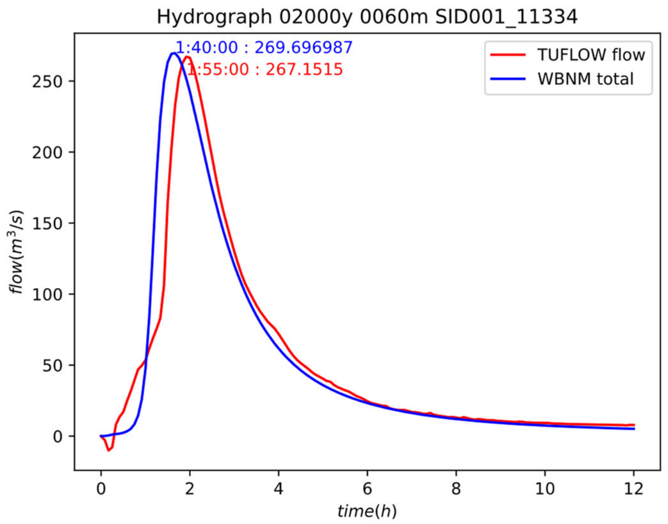


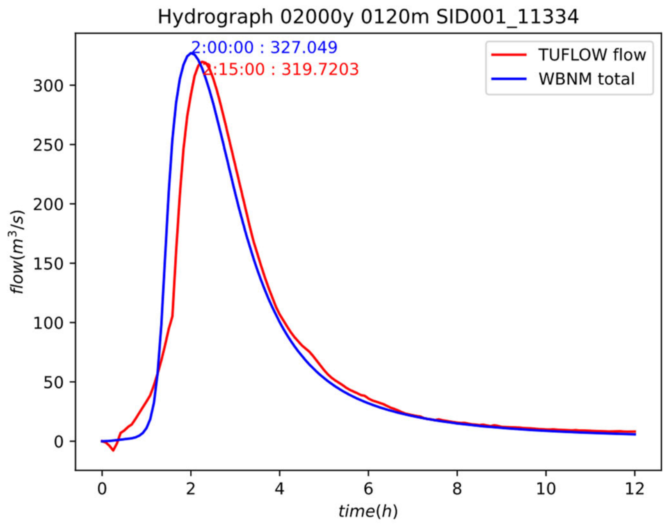
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.96	-5.7	0
5-year 120-minute	0.97	-6	-10
5-year 360-minute	0.99	-1.6	0
20-year 60-minute	0.95	-4.4	-10
20-year 120-minute	0.94	2.3	-10
20-year 360-minute	0.98	1.8	-5

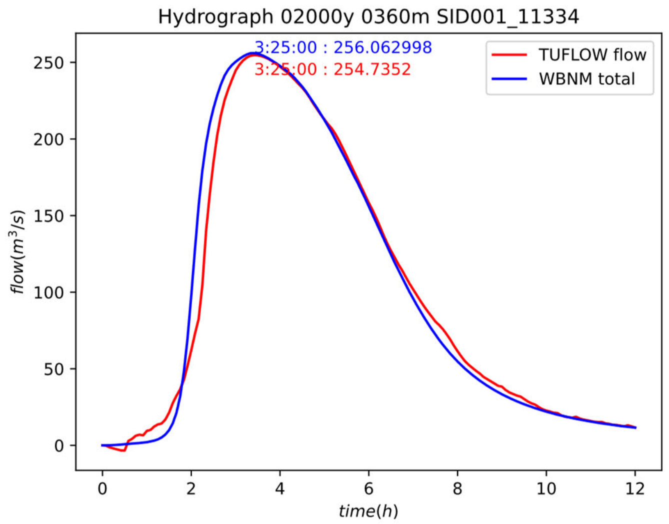




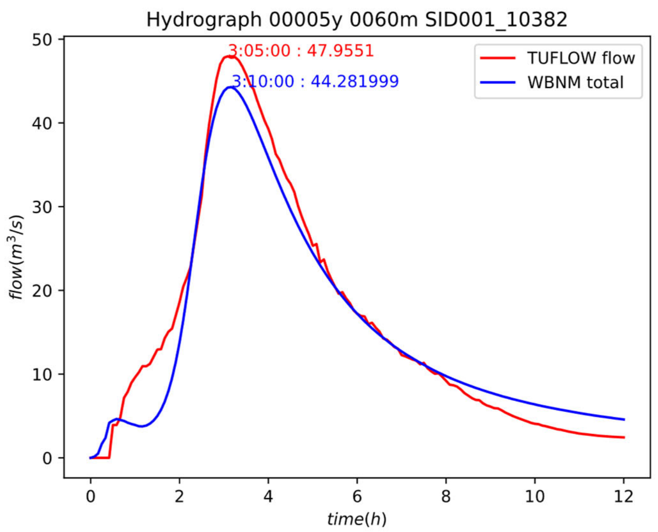


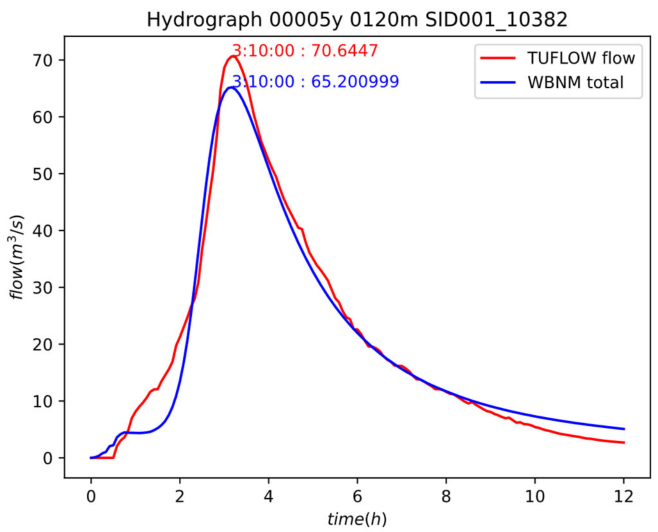


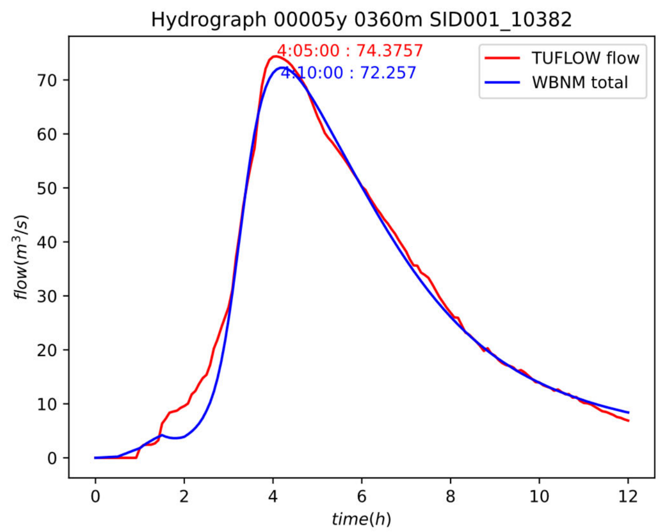


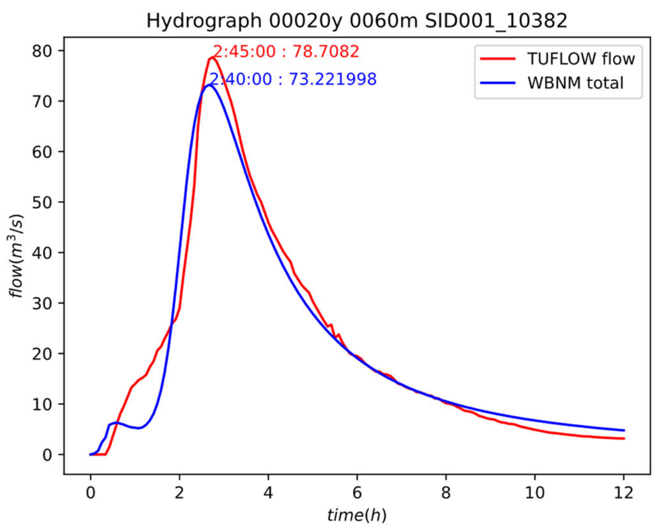


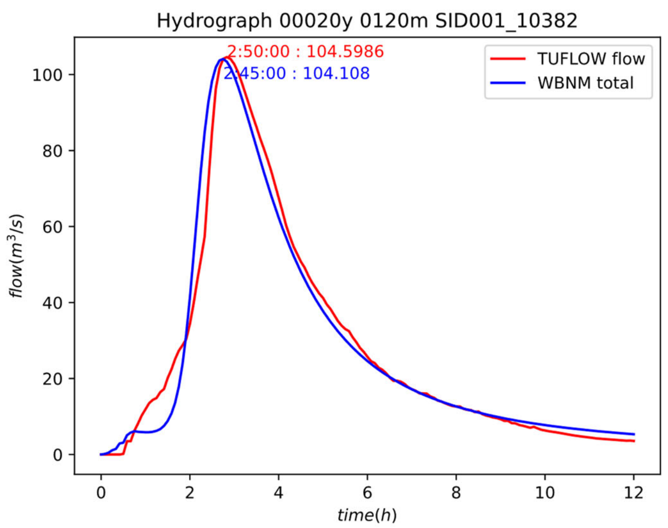
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.91	1.3	-15
100-year 120-minute	0.92	1.3	-15
100-year 360-minute	0.97	1.6	-5
2000-year 60-minute	0.87	1	-15
2000-year 120-minute	0.92	2.3	-15
2000-year 360-minute	0.98	0.5	0

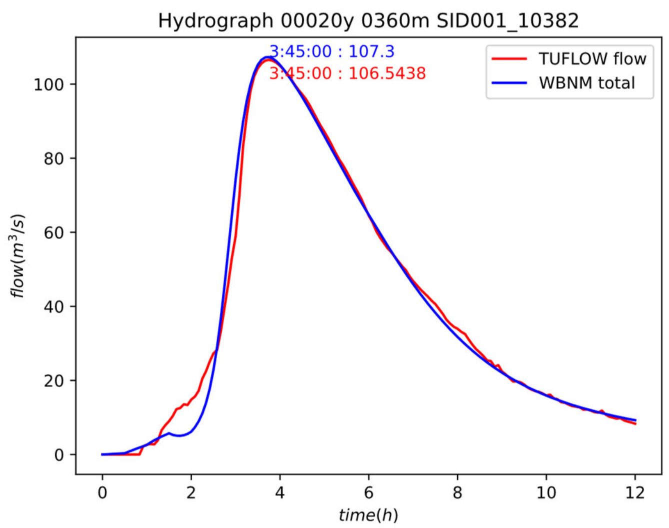




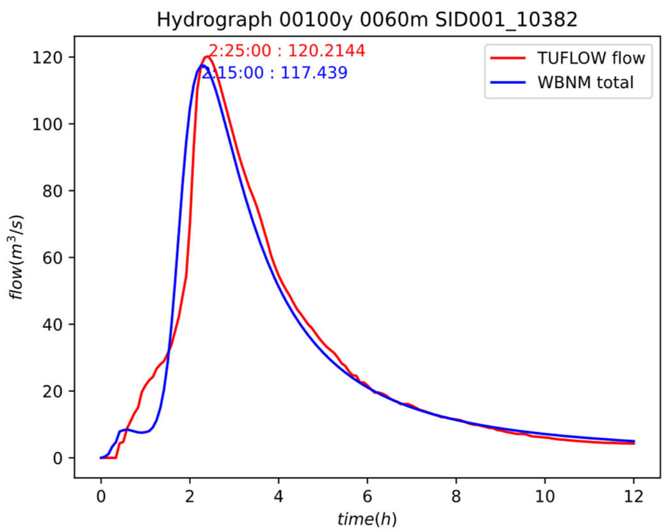


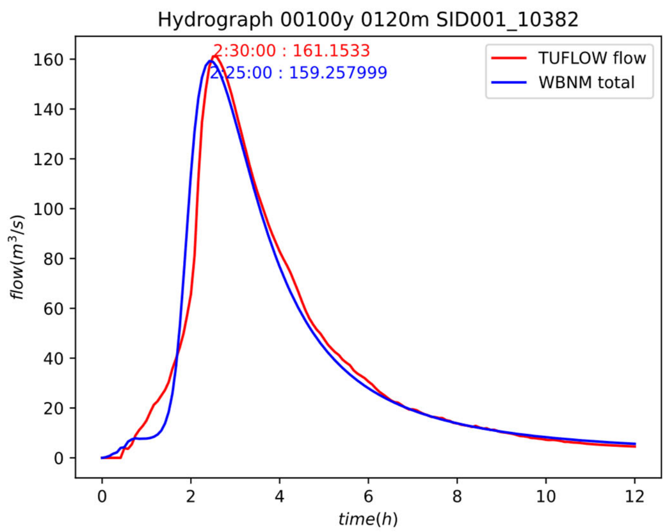


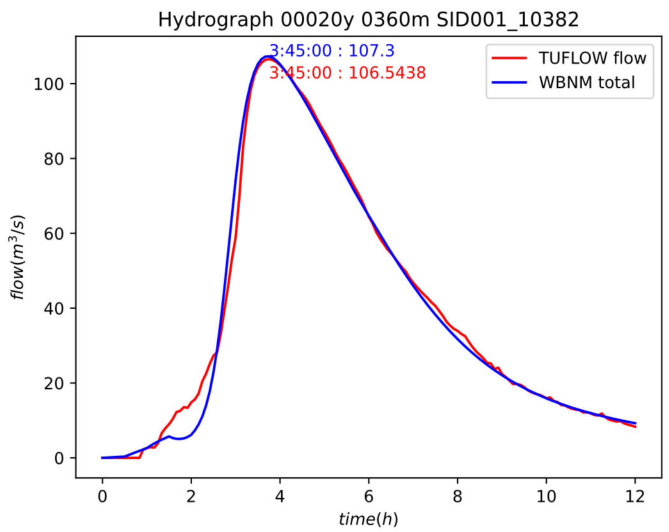


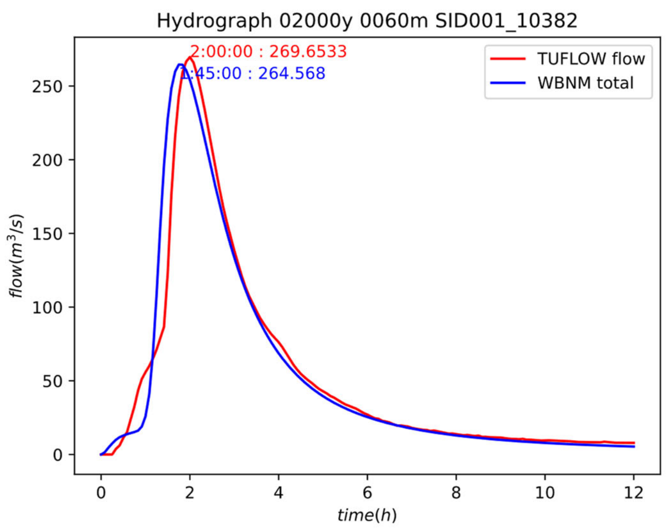


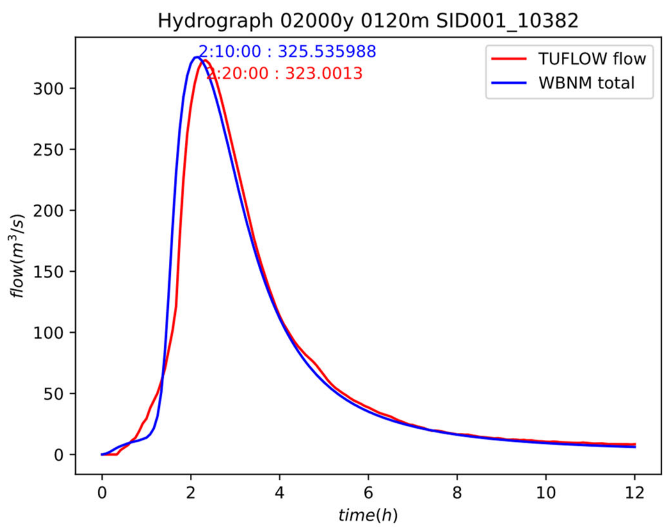
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.96	-7.7	5
5-year 120-minute	0.97	-7.7	0
5-year 360-minute	0.99	-2.8	5
20-year 60-minute	0.96	-7	-5
20-year 120-minute	0.97	-0.5	-5
20-year 360-minute	0.99	0.7	0

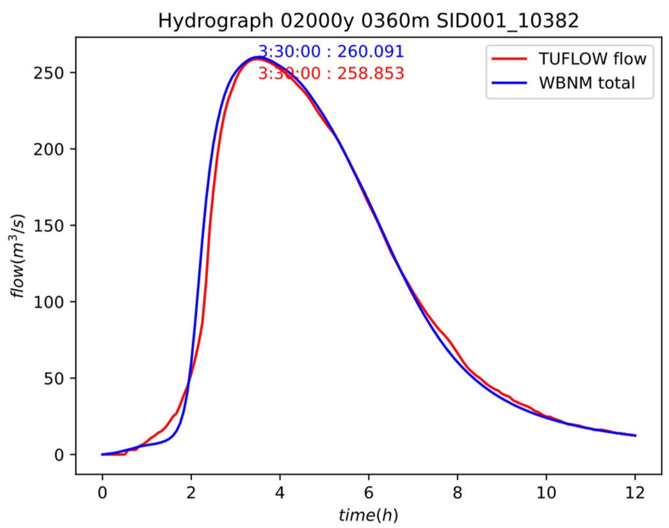




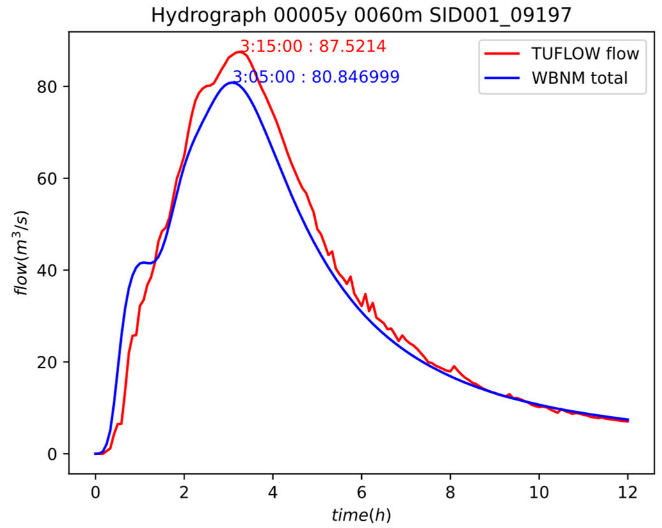


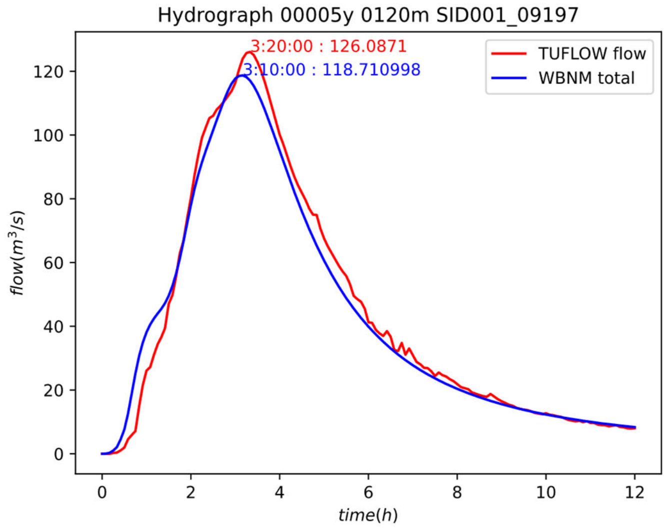


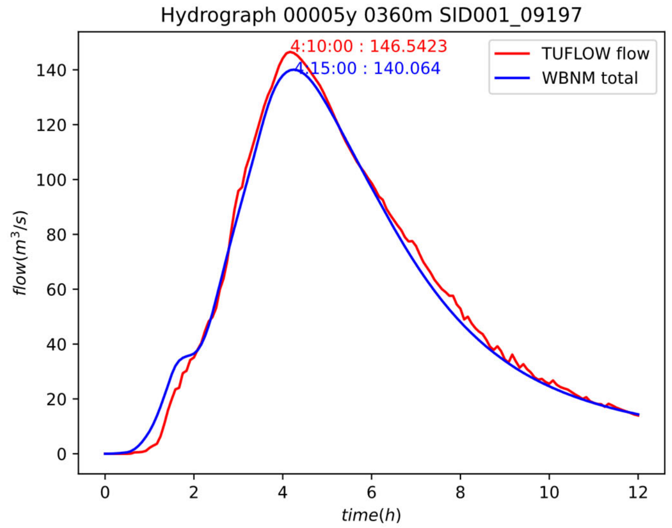


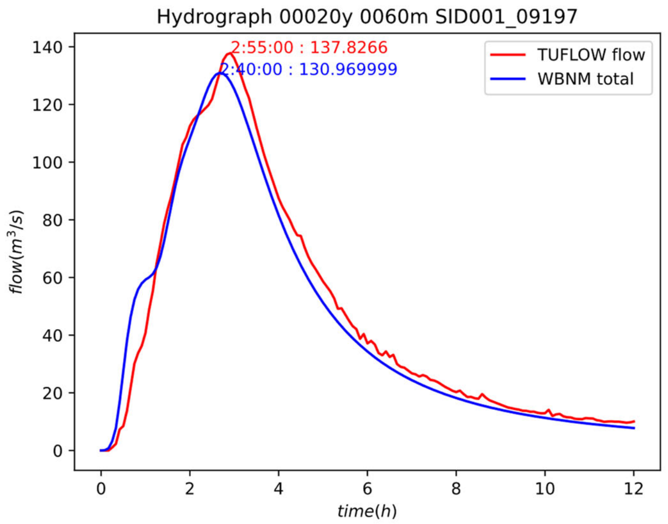


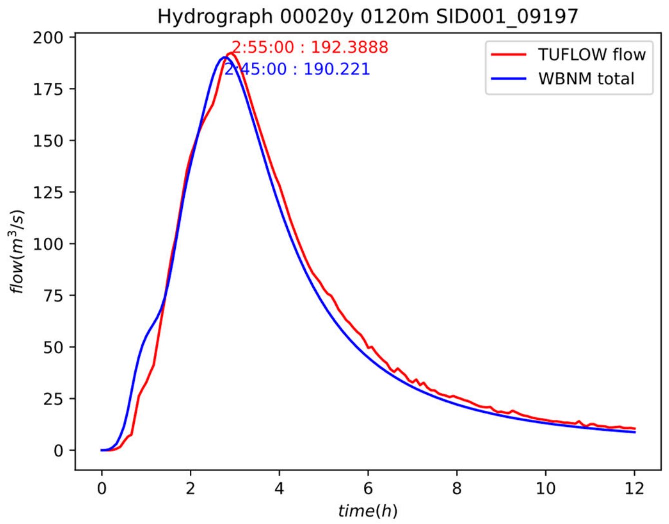
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.95	-2.3	-10
100-year 120-minute	0.96	-1.2	-5
100-year 360-minute	0.99	1	0
2000-year 60-minute	0.93	-1.9	-15
2000-year 120-minute	0.96	0.8	-10
2000-year 360-minute	0.99	0.5	0

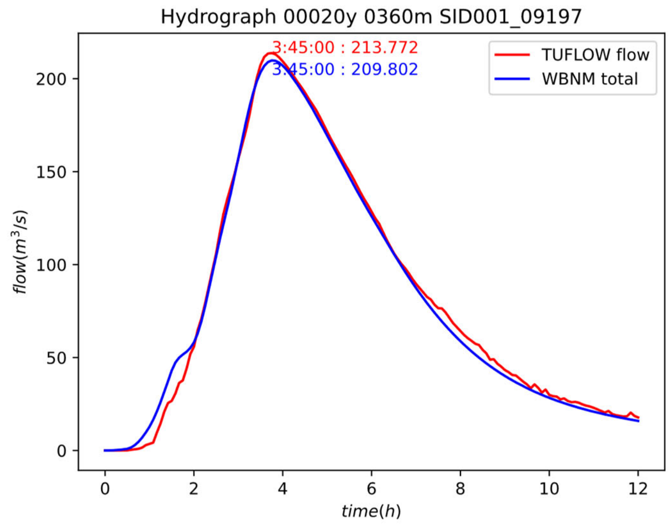




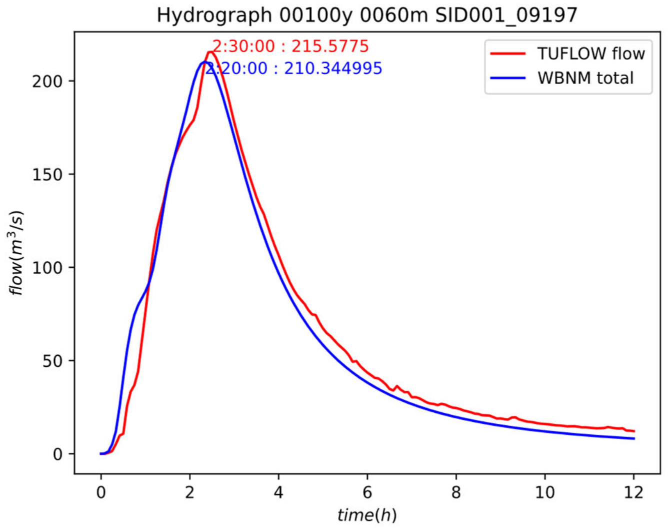


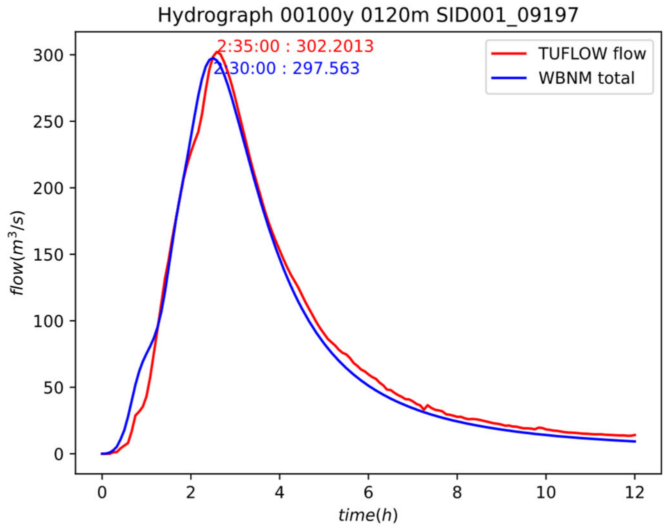


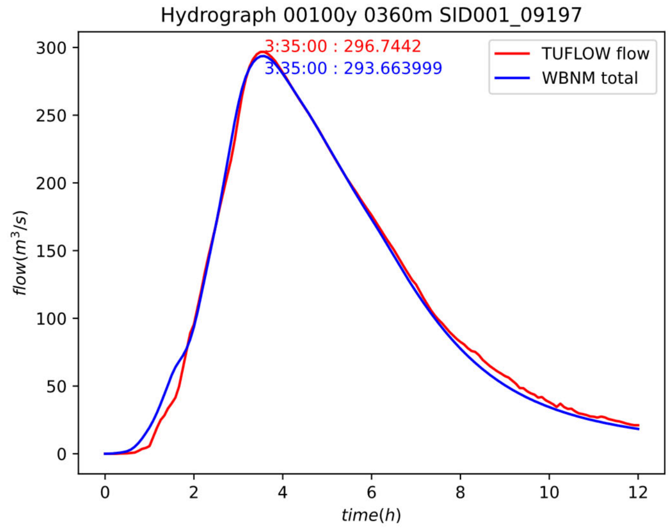


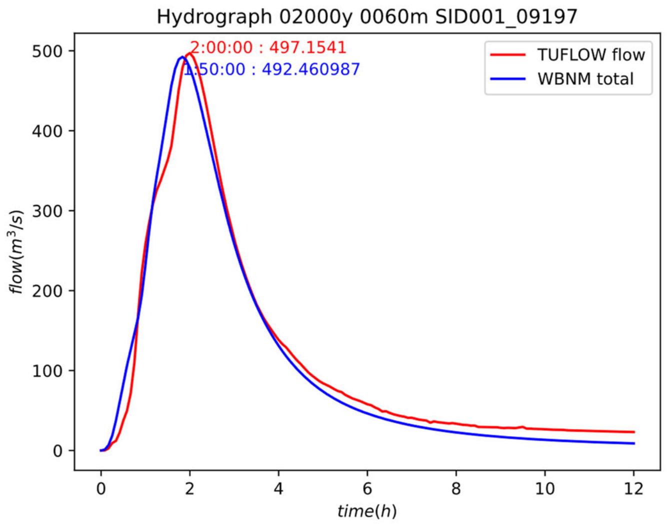


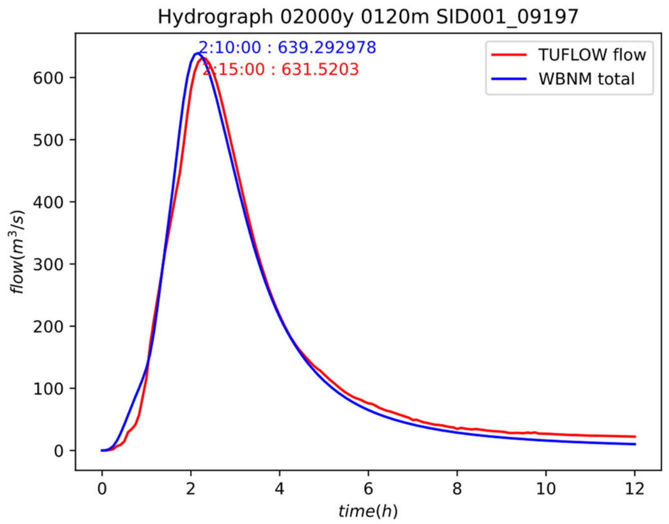
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.97	-7.6	-10
5-year 120-minute	0.98	-5.9	-10
5-year 360-minute	0.99	-4.4	5
20-year 60-minute	0.97	-5	-15
20-year 120-minute	0.99	-1.1	-10
20-year 360-minute	1.00	-1.9	0

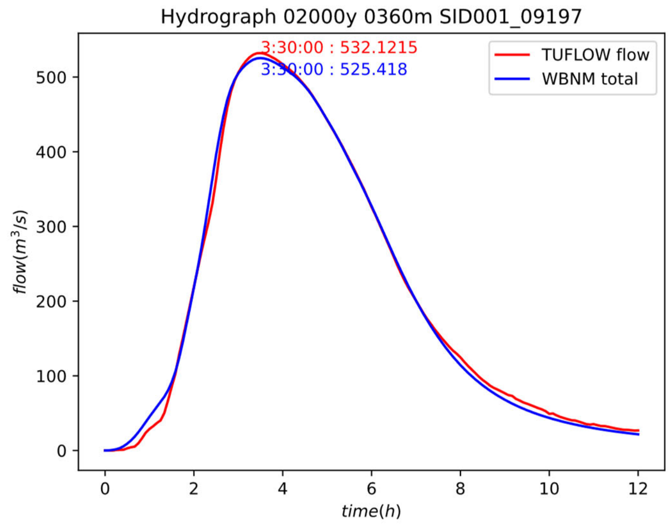




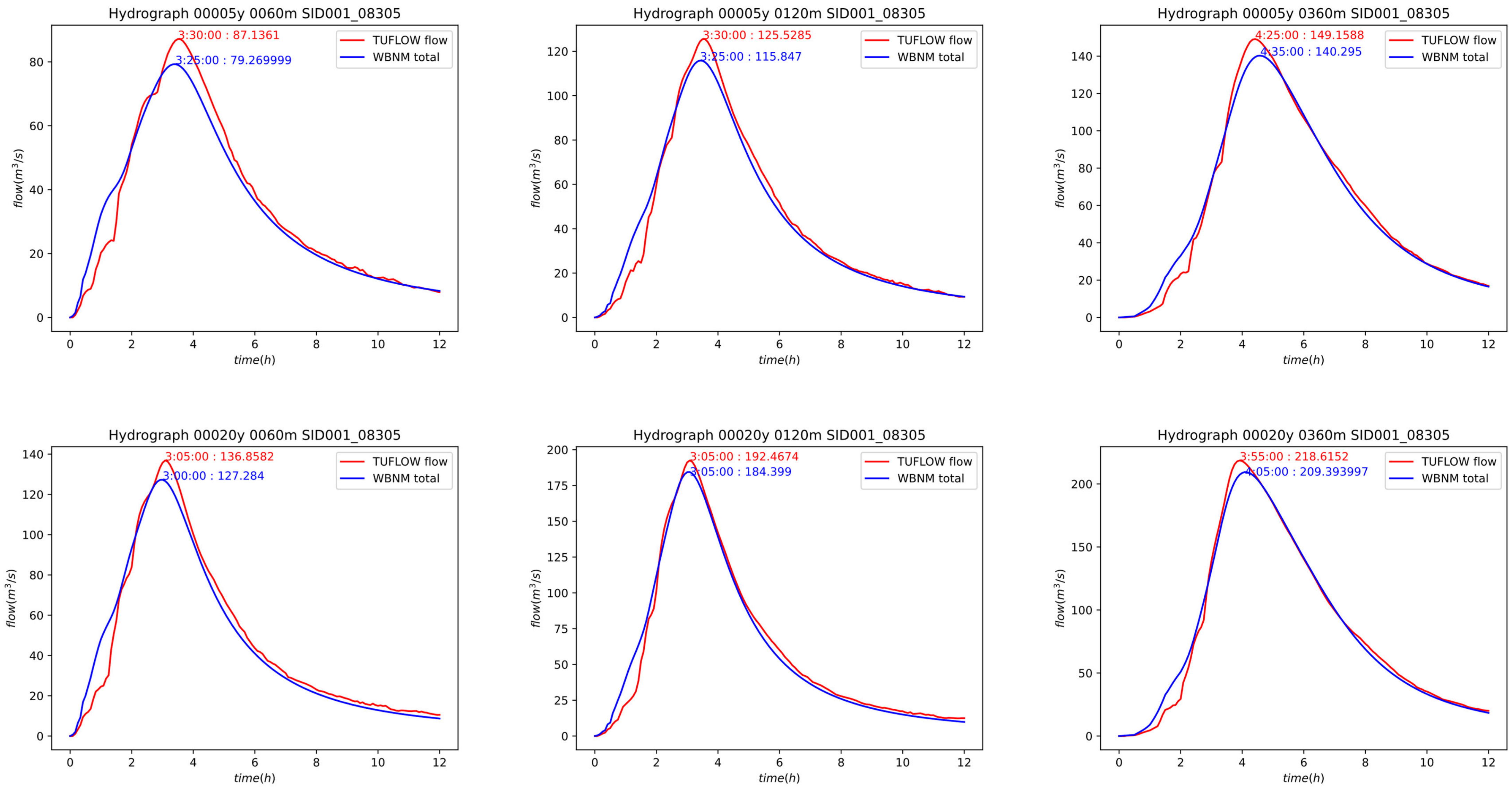




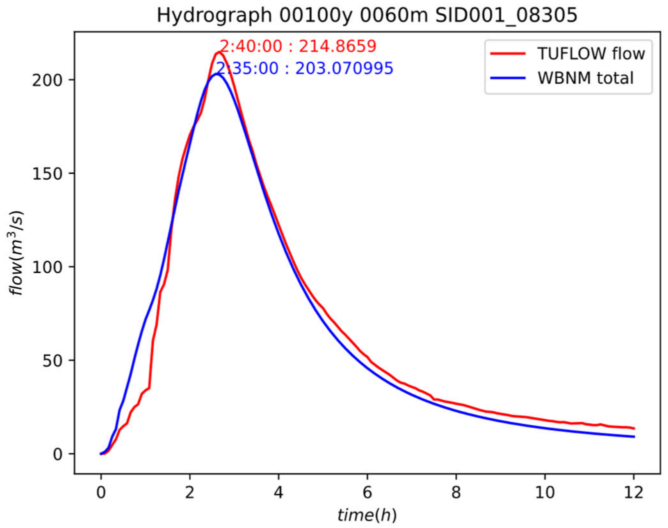


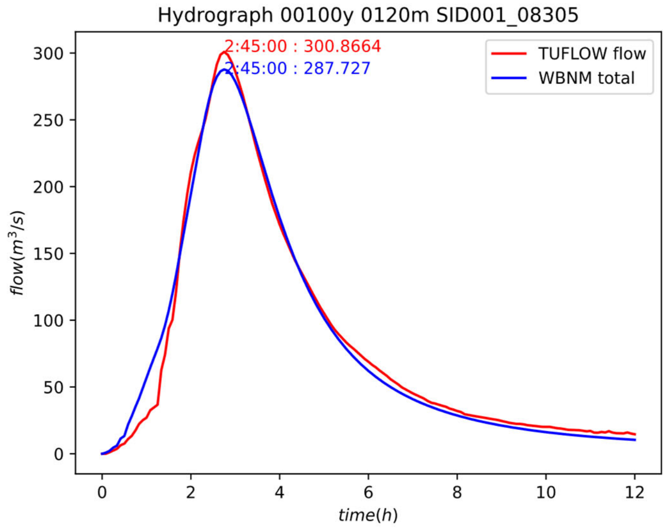


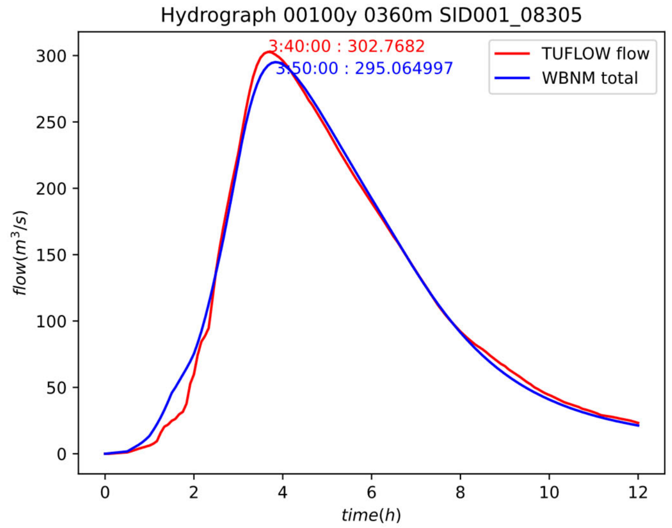
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.98	-2.4	-10
100-year 120-minute	0.99	-1.5	-5
100-year 360-minute	1.00	-1	0
2000-year 60-minute	0.98	-0.9	-10
2000-year 120-minute	0.99	1.2	-5
2000-year 360-minute	1.00	-1.3	0

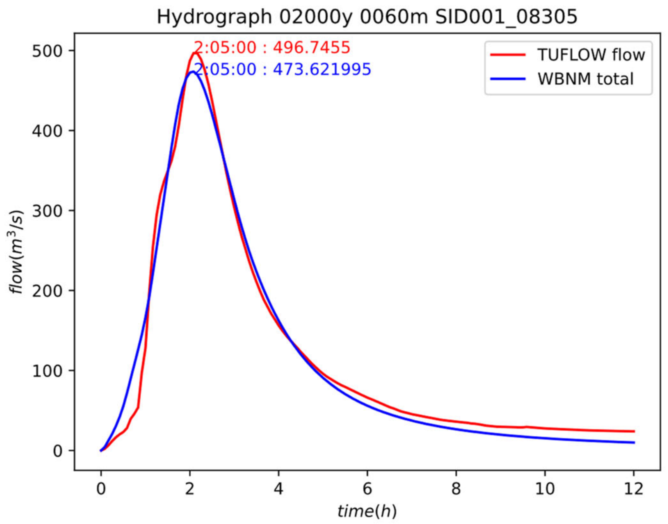


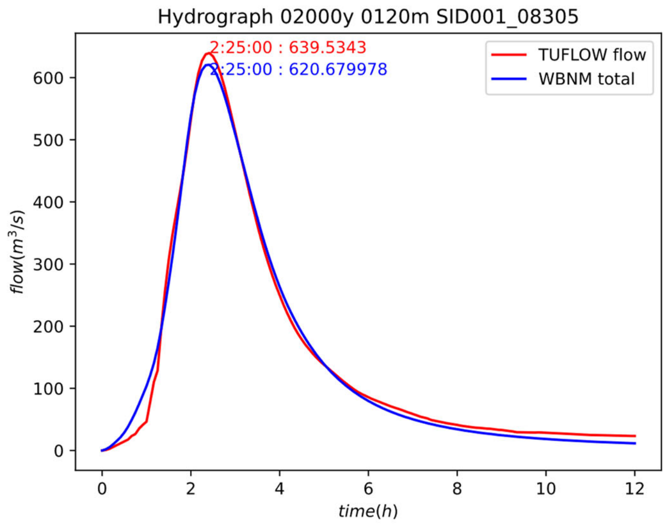
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.96	-9	-5
5-year 120-minute	0.98	-7.7	-5
5-year 360-minute	0.99	-5.9	10
20-year 60-minute	0.97	-7	-5
20-year 120-minute	0.98	-4.2	0
20-year 360-minute	0.99	-4.2	10

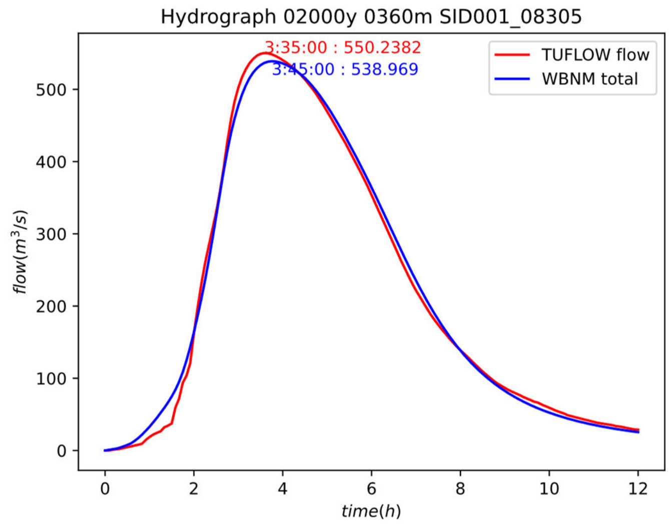




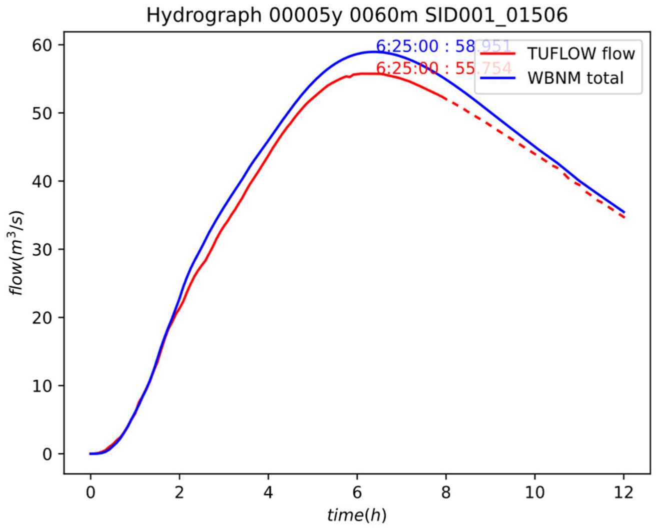


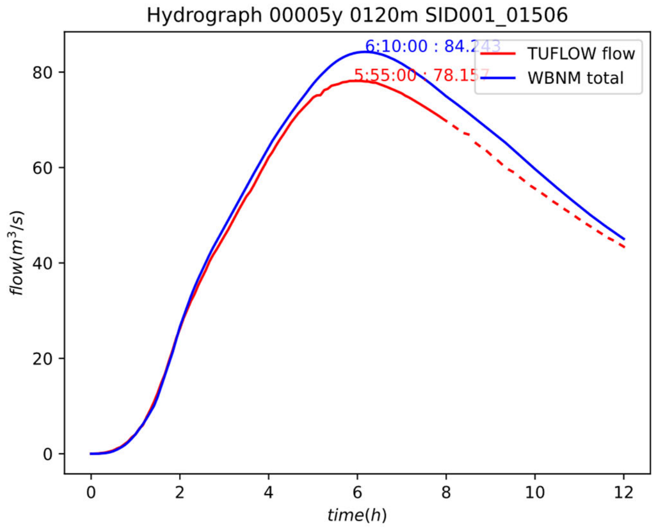


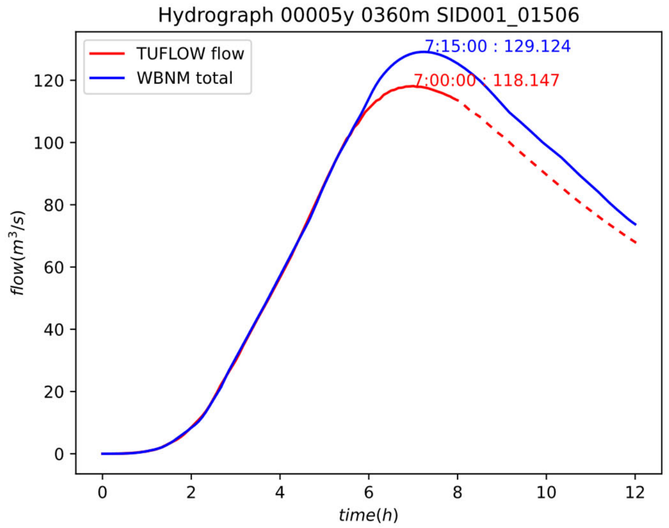


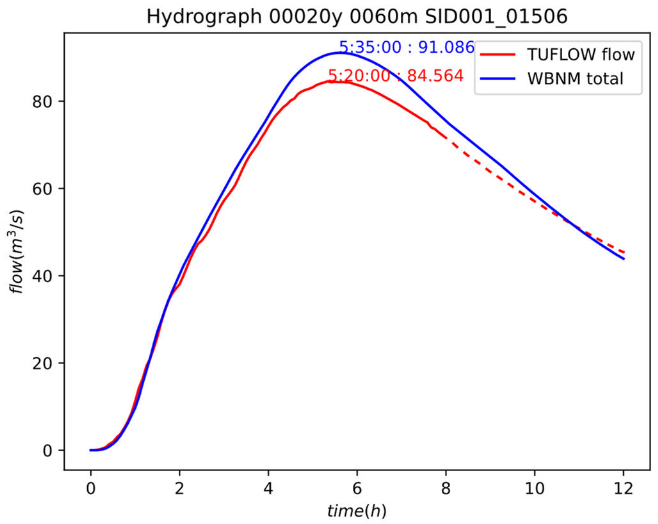


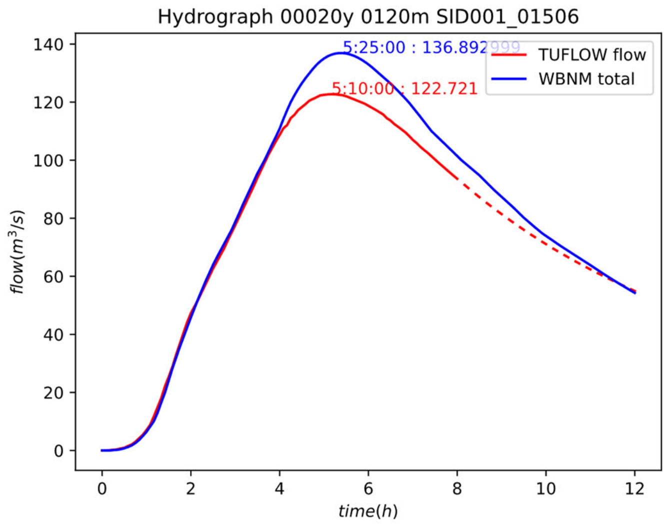
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.98	-5.5	-5
100-year 120-minute	0.99	-4.4	0
100-year 360-minute	0.99	-2.5	10
2000-year 60-minute	0.98	-4.7	0
2000-year 120-minute	0.99	-2.9	0
2000-year 360-minute	1.00	-2	10

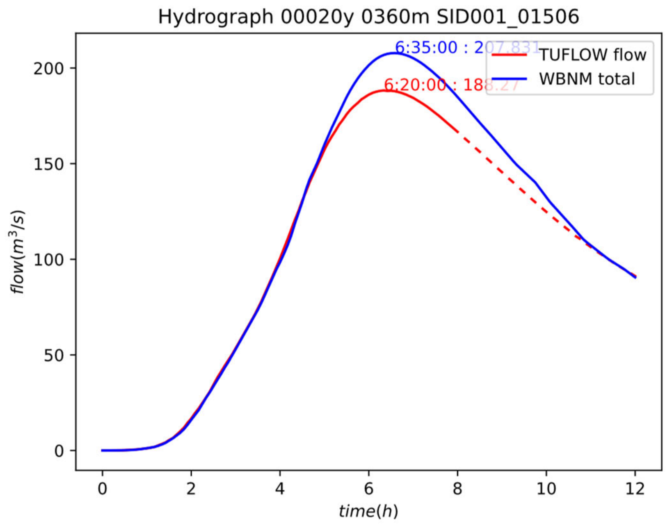




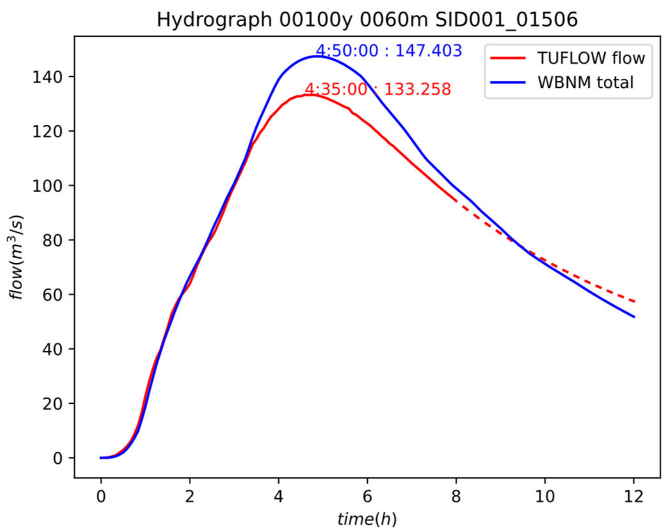


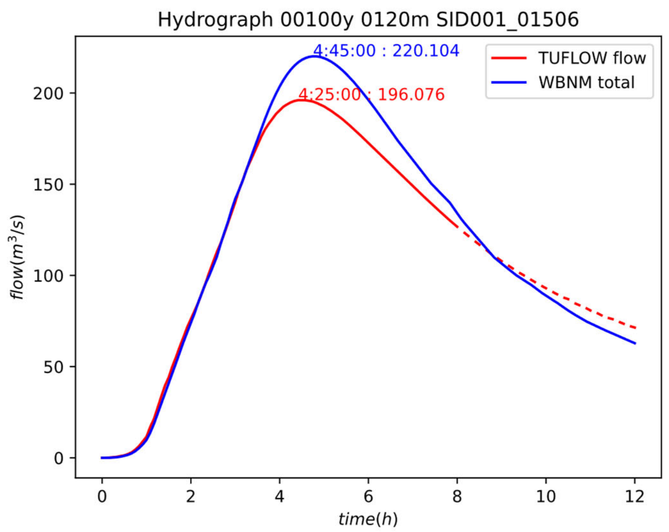


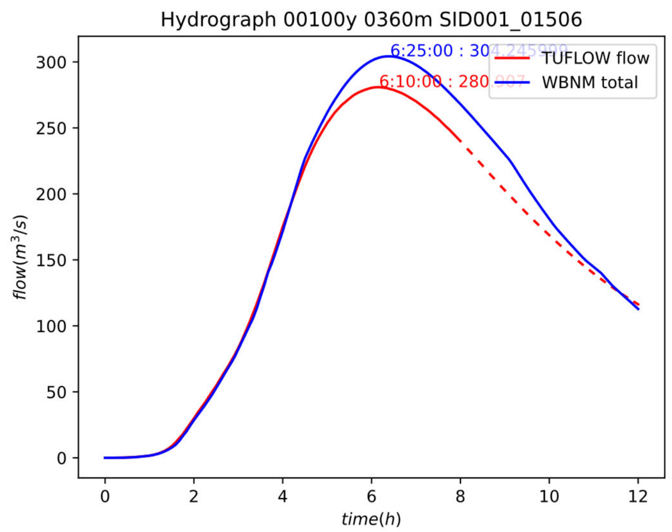


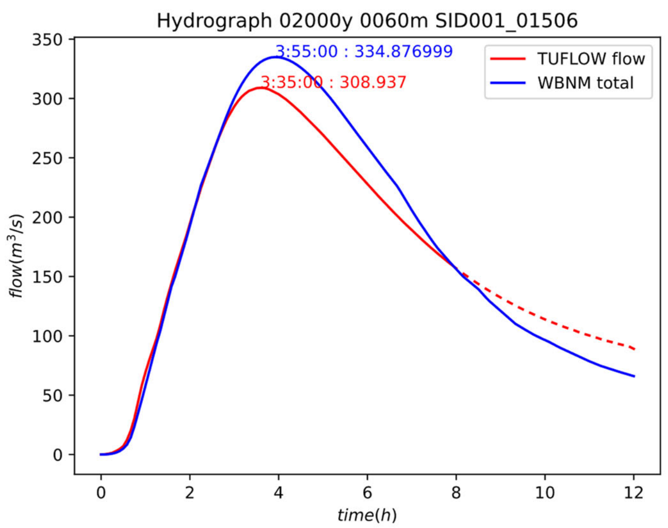


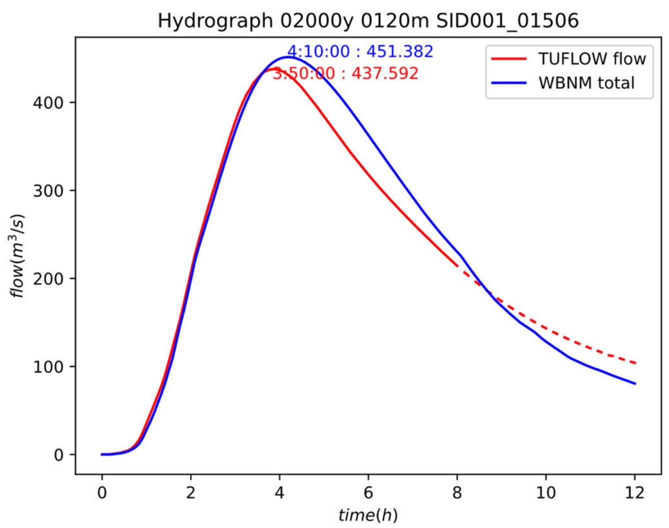
ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
5-year 60-minute	0.98	5.7	0
5-year 120-minute	0.98	7.8	15
5-year 360-minute	0.98	9.3	15
20-year 60-minute	0.98	7.7	15
20-year 120-minute	0.96	11.5	15
20-year 360-minute	0.98	10.4	15

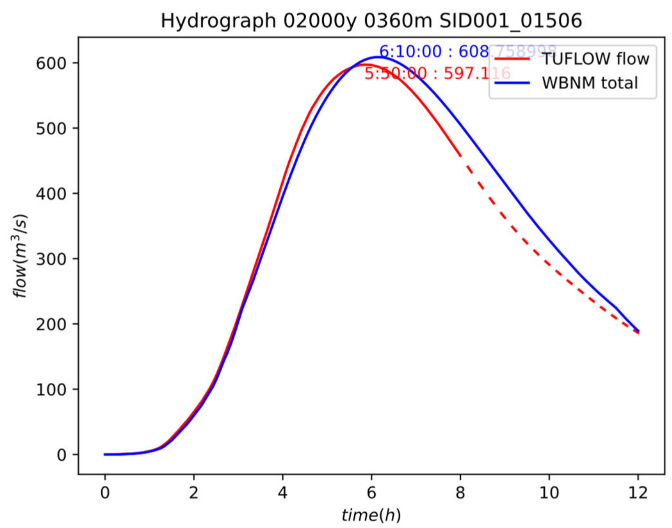












ARI Event and Duration	Nash-Sutcliffe Efficiency	Peak Ratio (%)	Difference in Timing (minutes)
100-year 60-minute	0.96	10.6	15
100-year 120-minute	0.95	12.3	20
100-year 360-minute	0.98	8.3	15
2000-year 60-minute	0.94	8.4	20
2000-year 120-minute	0.97	3.2	20
2000-year 360-minute	0.98	1.9	20

Annex E Sideling Creek Design Event Hydrologic Modelling

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Technical Note

Project	A11567 – RFD 2022 Major Update		
From:	Blair Filer		
Date:	05/07/2023	To:	Hester van Zijl (MBRC), Bonnie Beare, Elton Chong
Doc Ref:	T.A11567.022		
Subject:	Sideling Creek Design Event Hydrology Modelling and Results		

1.1 Overview

This Technical Note has been prepared to outline the design event hydrology modelling and results for the Sideling Creek catchment. The purpose of the modelling is to select 'critical' temporal patterns and 'critical' durations using the hydrology model when applying the latest Australian Rainfall and Runoff (ARR2019) guideline. For the remainder of this document the 'critical' temporal patterns and critical durations is referred to as the 'critical storm'. After reviewing the critical storms and associated results, a sub-set of these events were selected and simulated in the hydraulic model.

ARR2019 recommends the ensemble approach for design event modelling which uses 10 temporal patterns per duration. As a result, multiple durations and temporal patterns are required to be simulated. In addition, different sets of temporal patterns and areal reduction factors (ARF) are to be applied based on the size of the upstream catchment. As multiple points of interest (POI) have been selected for this project, POI have been grouped to accommodate the different temporal pattern sets and ARF.

With the critical storm selected based on the hydrology model, a sub-set was selected for the hydraulic model using a matrix. The matrix was developed using specified design event POI and their associated critical storm. At each POI, the matrix compared the peak discharge of its associated critical storm to another critical storm that was selected at a different POI. Critical storms were then included or excluded based on the similarities of the peak discharge, with the final sub-set representing the critical storm across all POI.

The POI for the RFD 2022 Major Update project include both 'Design Event Modelling' points to assist with design event selection when using ARR2019 methodology as well as the 'HEH points' used for the development of the HEH model. For clarification this Technical Note refers to POIs by their subclassification i.e 'HEH point' or 'Design Event Modelling point'.

1.2 Definitions

The definitions used throughout this Technical Note are as follows:

- Annual Exceedance Probability (AEP) – this terminology is used when referring to design rainfall-runoff events using Australian Rainfall and Runoff 2019 (ARR2019) methodology.
- Critical Temporal Pattern – this is the selected temporal pattern when choosing from multiple temporal patterns for a given duration. ARR2019 guideline outlines that the ensemble method has 10 temporal patterns per duration. For this study the critical temporal pattern is defined as the 'one above the mean'.
- Critical Duration – this is the selected duration from all the critical temporal patterns (i.e. all durations). For this study, this maximum of all the critical temporal pattens.
- Critical storm– this is the selected critical duration for a given location / point / sub-catchment. For this Technical Note the critical storm is based on the Design Event Modelling points.

1.3 Document Setup

The remainder of this Technical Note includes the following sections:

- Design Event Modelling Points – this section details the selection of the points across the catchment and their grouping for design event modelling and critical storm selection.
- Design Event Modelling Inputs – this section contains the details of the hydrologic model and input parameters for the design event modelling.
- Design Event Results – the section details the critical storm selected for each Design Event Modelling point, and the sub-set for simulation in the hydraulic model.

2 Design Event Modelling Points

2.1 Nomination

MBRC supplied initial suggested points of interest (POI) at the start of the RFD 2022 Major Update project. These POI have been reviewed, refined, and expanded by BMT during this project for the purposes of undertaking the HEH modelling and the ARR2019 Design Event selection. The review of the POI ensured that confluences, roads, future development area, gauges, and catchment outlets were considered in the nomination of the POI. The POI were then divided into 'HEH points' for establishment of the WBNM HEH model and 'Design Event Modelling' points. Both sets of POI are shown in Figure 2.1. The notable differences are described in 'Sideling Creek HEH Modelling and Results' Technical Note.

2.2 Grouping

ARR2019 sets out an ensemble approach to design event modelling whereby, for each storm duration of a given AEP, an ensemble of 10 rainfall temporal patterns are to be used. ARR2019 also sets out that the rainfall intensity-frequency-duration (IFD) curves are to be scaled using areal reduction factors (ARF). Both parameters are applied using the upstream catchment size for a given Design Event Modelling point. Given the Sideling Creek catchment has more than one Design Event Modelling point, the points were grouped together to limit the number of hydrologic model simulations.

To group the Design Event Modelling points, an approach was undertaken where points with similar upstream catchment sizes were assessed together. The grouping was determined in consultation with Council using the following steps:

1. Temporal Pattern boundaries: ARR2019 gives guidance to the set of temporal patterns applied based on the upstream contributing area to a given point. These sets include 'point' temporal patterns for upstream catchment size less than 75km², and 'areal' temporal patterns for catchment areas greater than 75km². Areal temporal pattern sets also change with the increase in catchment sizes; hence there are 9 different boundaries for areal temporal patterns. The initial upper and lower boundaries for the groupings were spilt using the point and areal temporal pattern boundaries from ARR2019.

2. Areal reduction factor: ARF scale the point derived IFD curve using the AEP magnitude, storm burst duration, and catchment size. The ARF is a contributor to volume of water in the model, hence it was decided to limit the reduction of rainfall depth to approximately a 5% from the upper to lower boundary. The initial groupings were split to meet this criterion, where the point temporal patterns were split into 5 groupings and most areal temporal pattern groups were split into two different groups (a total of 6 different areal temporal pattern groupings were used for this project).

3. The applied ARF for each grouping was designated to approximately the halfway point between the upper and lower bounds of each group. This further limited the reduction of volume to approximately 2-3%.

Table 2.1 summarises the grouping names (as specified by Council), their upper and lower bounds, the applied catchment areas for the ARF, and the temporal pattern applied. The design event modelling points for each grouping are also presented in Table 2.1 and are shown in Figure 2.1. For the Sideling Creek catchment, 3 groups were required to be simulated.

Table 2.1 Design Event Point Groupings

RFD Naming Convention	Catchment Area Range (lower to upper bounds)	Applied Catchment Area	Temporal Pattern Applied	Design Event Modelling Point
ARFa	$0km^2$ to $1.5km^2$	None, ARF = $1km^2$	Point	
ARFb	$1km^2$ to $5km^2$	$2.5km^2$	Point	
ARFc	$5km^2$ to $15km^2$	$10km^2$	Point	SID004_00814, SID010_01949, SID001_10382
ARFd	$15km^2$ to $35km^2$	$25km^2$	Point	SID001_08305
ARFe	$35km^2$ to $75km^2$	$50km^2$	Point	SID001_01506
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 $1000km^2$	

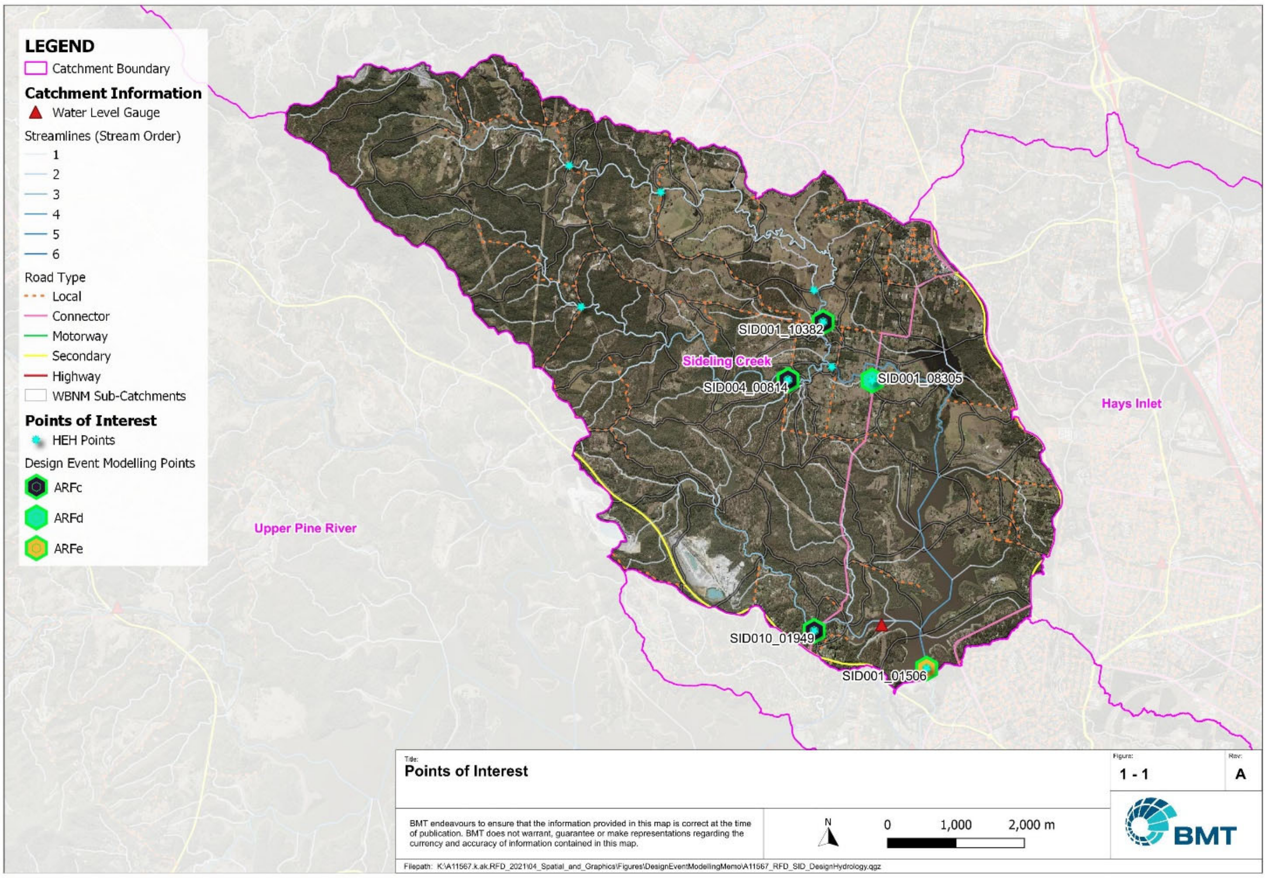


Figure 2.1 Points of Interest

3 Design Event Modelling Inputs

3.1 WBNM Model

The hydrologic model used in this assessment has been updated to have hydraulic equivalence at specified POI (i.e match the hydrographs of the hydraulic model) by developing a hydraulic equivalent hydrologic (HEH) model. This hydraulic equivalence was undertaken to provide confidence in the selection of the critical storm, and to match hydraulic model results. Details on the HEH methodology and results are described in the 'HEH methodology' Technical Note and the 'Sideling Creek HEH Modelling and Results' Technical Note.

Two variants of the model with different fraction impervious data were used for the design event modelling. These variants are as follows:

- Existing conditions (2022) - the 2020 fraction impervious data applied for the calibration and HEH modelling, was also applied to the existing conditions. The fraction impervious was calculated using the existing effective impervious area (EIA) raster supplied by Council.
- Future conditions - an envelope of the maximum fraction impervious between the existing conditions EIA raster and the ultimate conditions EIA raster (supplied by Council) was applied.

3.2 Parameters

Specific details with regard to setting up the design event hydrology model are summarised in Table 3.1. The parameters were setup within StormInjector version 1.3.7_HL and the simulated hydrologic models were simulated using the supplied WBNM executable (2017c) within StormInjector.

Table 3.1 Design Event Model Parameters

Parameter	Comment
Events	The following ARR2019 events and durations were simulated in the WBNM model: AEP events– 20%, 10% 5%, 2%, 1%, 0.1%, and 0.05% Durations – 30-minutes to 2880-minutes (48-hours)
Pre-burst	Pre-burst rainfall depths were included from ARR Data Hub. The generalised short-duration method (GSDM) temporal pattern was applied as the pre-burst temporal pattern[1]. In consultation with Council and Water Technology the temporal pattern was applied in the following manner: 1. Apply median pre-burst depth values distributed using the 1hr GSDM pattern for storm burst durations of 60-minutes (1-hours) and less. 2. Apply median pre-burst depth values distributed using the 2hr GSDM pattern for storm burst durations of 90-minutes (1.5-hours) and 120-minutes (2-hours). 3. Apply median pre-burst depth values distributed using the 4hr GSDM pattern for storm burst durations of 180-minutes (3-hours) and greater.
Initial Loss	The global initial loss was applied from the ARR Data Hub. The global initial loss was applied to the pre-burst rainfall described in the Pre-burst row of this Table (above). The global initial loss value from the ARR Data Hub was found to be lower than the average of the calibrated initial loss values. Therefore, in consultation with Council, the ARR Data Hub was adopted as it is more conservative approach.
Continuing Loss	A calibration continuing loss of 1mm/hr was adopted in consultation with Council. Calibration required a lower continuing loss than that the loss specified from the ARR Data Hub as the continuous loss influences the water levels within Lake Kurwongbah.

[1] BoM (2003), "The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"

Parameter	Comment
IFD	LIMB 2020 IFD curves were applied at the centroid of all sub-catchments. These were downloaded within StormInjector via the ARR Data Hub. Factoring to the IFD in the different variants of the hydrology model was applied as follows: • No factoring was applied for the existing conditions. • An increase of 20% was applied for future conditions.
Temporal Patterns	The 'East Coast North' (point and areal) temporal patterns were applied and were retrieved from the ARR Data Hub. Temporal pattern sets were applied based on the Design Event Modelling point groupings, as indicated in the 'Applied Temporal Pattern' column of Table 2.1. Embedded bursts within temporal patterns were smoothed using the StormInjector software. Where smoothing exceeded 40% these simulations were removed from the critical storm selection as recommended in ARUP (2021)[2] and discussed with Council.
Areal Reduction Factors	The ARF were calculated using the East Coast North coefficients available from the ARR Data Hub. ARFs were applied to each Design Event Modelling point group as per 'Applied Catchment Area' column in Table 2.1.

[2] ARUP (2021), "Regional Flood Database ARR 2019 Pilot Study: Part 1 Methodology Report & Part 2 Pilot Study Report"

4 Design Event Results

4.1 Critical Simulation for each Design Event Modelling point

Once the hydrologic models were simulated for all groups in Table 2.1, the critical storm for each Design Event Modelling point was selected. Assigning the critical temporal pattern and duration for each point was based on the methodology prescribed in the ARUP (2021) and calculated using the StormInjector software. The critical was selected using the associated grouping for a given Design Event Modelling point:

1. The mean peak discharge was calculated from the peak discharge of the 10 temporal patterns in each duration.

2. The critical temporal pattern was then selected using the first peak discharge above the mean.

3. The critical duration was the maximum of the critical temporal pattens (also referred to 'max of means'). With the associated grouping to the Design Event Modelling point, this is the critical storm for the given point.

Table 4.1 to Table 4.7 documents the critical storms of each Design Event Modelling point for the AEP events of 20%, 10% 5%, 2%, 1%, 0.1%, and 0.05% respectively. The critical storms were selected using the existing conditions of the hydrologic model.

Table 4.1 Critical Storm at each Design Event Modelling point - 20% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	270	5	64.8
SID010_01949	ARFc	180	6	51.9
SID001_10382	ARFc	270	5	83.4
SID001_08305	ARFd	270	4	157.8
SID001_01506	ARFe	720	5	165.6

Table 4.2 Critical Storm at each Design Event Modelling point - 10% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	180	8	91.5
SID010_01949	ARFc	180	4	69.0
SID001_10382	ARFc	180	8	115.4
SID001_08305	ARFd	360	7	219.3
SID001_01506	ARFe	540	10	238.1

Table 4.3 Critical Storm at each Design Event Modelling point - 5% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	180	8	113.3
SID010_01949	ARFc	180	8	85.9
SID001_10382	ARFc	180	4	145.4
SID001_08305	ARFd	360	7	271.0
SID001_01506	ARFe	540	9	283.3

Table 4.4 Critical Storm at each Design Event Modelling point - 2% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	270	7	133.1
SID010_01949	ARFc	120	8	95.7
SID001_10382	ARFc	270	7	180.7
SID001_08305	ARFd	270	7	345.5
SID001_01506	ARFe	360	6	380.8

Table 4.5 Critical Storm at each Design Event Modelling point - 1% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	270	7	150.3
SID010_01949	ARFc	120	8	108.0
SID001_10382	ARFc	270	7	205.6
SID001_08305	ARFd	270	7	396.6
SID001_01506	ARFe	360	4	458.7

Table 4.6 Critical Storm at each Design Event Modelling point – 0.1% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	270	7	218.6
SID010_01949	ARFc	120	1	164.5
SID001_10382	ARFc	270	7	300.1
SID001_08305	ARFd	270	7	277.1
SID001_01506	ARFe	360	10	649.4

Table 4.7 Critical Storm at each Design Event Modelling point – 0.05% AEP

Design Event Modelling Point Name	Grouping	Duration (minutes)	TP (1- 10)	Existing Conditions Peak Discharge (m^3/s)
SID004_00814	ARFc	120	8	233.8
SID010_01949	ARFc	120	1	183.6
SID001_10382	ARFc	270	7	334.6
SID001_08305	ARFd	270	7	641.9
SID001_01506	ARFe	360	10	716.3

4.2 Selection method for the sub-set of the critical storms

A sub-set of the critical storms were selected for the hydraulic model to limit the computational time and to exclude simulations which will not be representative of the AEP flood surface across the catchment. To select the sub-set of simulations, BMT created a matrix with the critical storms at each Design Event Modelling point. At a given Design Event Modelling point, the matrix was used to compare the peak discharge of its critical storm to the peak discharge of another point's critical storm[3].

Within the matrix, understanding the peak discharge difference from the critical storm to another critical storm was best shown as a relative difference ratio (in percentage). This relative difference ratio allowed a greater understanding of the effect would occur to the peak discharge when simulating one event over another.

Using the matrix ('design event matrix'), a sub-set of simulations were selected by minimising the difference (the percentage) in peak discharge at every Design Event Modelling point to the peak discharge from their associated critical storm. In general, if the peak discharge of the selected simulation is significantly lower or higher than the critical storm's peak discharge, another storm was selected.

4.3 Description of Design Event Matrices

The development of the matrices for the results and the selection of the sub-set are explained in the example below. This example has 5 Design Event Modelling points and 5 critical storms (identified as 'simulations' in the example). The development of the matrix and selection of the sub-set is as follows:

1. The 5 Design Event Modelling points are listed in the rows of the matrix. See Figure 4.1 for an example of Points 1, 2, 3, 4 and 5.

2. The 5 critical storms (simulations) are the columns of the matrix. See Figure 4.1 for an example of Simulation 1, 2, 3, 4 and 5 which are the critical storm of the 5 Design Event Modelling points. The naming of each simulation in the matrix will be as follows: the grouping number from the 'RFD Naming Convention' column in Table 2.1, the critical duration in minutes, and the critical temporal pattern number from 1 to 10 in brackets with a 'TP' in front. An example is 'ARFa 120 (TP1)' for the 120-minute (2-hour) duration using temporal pattern 1 applied from the ARFa grouping.

3. In Figure 4.1, the critical storm for each Design Event Modelling point has its cell highlighted in green with a '0.0%'. For example, going across the row of Point 1, the cell at Simulation 2 highted in green, therefore it is the critical storm of Point 1. And for Point 2, the critical storm is Simulations 1,

[3] The underlying assumption of the matrices is that peak discharge produces peak water level. This assumption is based on the Pine River catchments, including Sideling Creek catchment being largely conveyance dominated.

Point 3 is Simulation 3, and so on. It is noted that a simulation (down the column) can have more than one highlighted green cells as the multiple Design Event Modelling points can have the same critical storm. However, there can only be one green highlight cell for each Design Event Modelling Point (across the row).

Design Event Modelling Point Name	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
Point 1		0.0%			
Point 2	0.0%				
Point 3			0.0%		
Point 4				0.0%	
Point 5					0.0%

Figure 4.1 Example matrix with the critical storm only

4. Once the critical storm for each Desing Event Modelling point has been identified, the next step is to fill in the other cells of the matrix. For each Simulation (1 to 5), the peak discharge for the critical duration is extracted for each Point (1 to 5). An example of the peak discharge from each critical duration (within each of the 5 simulations) for Point 1 is shown in the first row of Figure 4.2 (indicated as 'Point 1 Discharge'). Point 1's critical duration has a peak discharge of 236.68m^3/s for Simulation 1, 233.8m^3/s for Simulation 2, 243.7m^3/s for Simulation 3, and so on. The critical storm for the Point 1 Discharge is also highlighted in green in Figure 4.2.

   The peak discharge is then converted into the relative difference ratio (in percent) using Equation 1. In Equation 1, the critical storm is indicated as 'Simulation Critical' and the critical duration used for the comparison is indicated as 'Simulation X'. An example of the final calculated ratios are shown in the second row of Figure 4.2 (indicated as 'Point 1 Percentage'), where Simulation 1 would indicate that the peak discharge of Point 1 would be 1.2% higher than the critical storm (236.68m^3/s for Simulation 1 compared to 233.8m^3/s for the critical storm). Simulation 2 is 0.0% as this is the critical storm. For Simulation 3 the peak discharge is 4.2% higher, for Simulation 4 the peak discharge is 1.2% lower and so on.

$$\frac{(Simulation\ X - Simulation\ Critical)}{Simulation\ Critical} \times 100 \qquad (1)$$

   Note that final design event matrices only present the relative difference ratio in percentages (and not the peak discharge).

Design Event Modelling Point Name	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
Point 1 Discharge	236.6	233.8	243.7	230.9	228.9
Point 1 Percentages	1.2%	0.0%	4.2%	-1.2%	-2.1%

Figure 4.2 Example matrix for calculation of the relative difference ratio

5. The next highlighting of the matrix is those percentages that are those outside a target range, where those highlighted in red are significantly higher and those in yellow are significantly lower. For this study, a ±10% target range was selected to be the upper and lower bounds. As shown in Figure 4.3, Simulation 1 is significantly lower (<-10%) at Point 3 and Point 5, where Simulation 2 is significantly higher (>+10%) at Point 2 whilst being significantly lower (<-10%) at Point 3 and 5. Simulation 3 has no percentage outside the target range, and so on.

Design Event Modelling Point Name	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
Point 1	1.2%	0.0%	4.2%	-1.2%	-2.1%
Point 2	0.0%	11.5%	-7.5%	-12.3%	-14.2%
Point 3	-10.4%	-10.5%	0.0%	15.3%	-5.9%
Point 4	-8.4%	-8.9%	5.5%	0.0%	-1.5%
Point 5	-39.3%	-39.5%	-3.7%	-7.9%	0.0%

Figure 4.3 Example matrix with target range highlighting

6. Lastly, the final highlighting is the sub-set of simulations to be included in the hydraulic model. Figure 4.4 illustrates the selected simulations with their headers highlighted in light blue. The example shows Simulation 1, 3, and 5 will be included in the hydraulic model runs.

   To select this sub-set of critical storms, combinations of critical storms were trialled, where the maximum relative difference ratio at each point was calculated for each combination (across the row). If the maximum at a given point is less than lower bounds of significance (-10%), another simulation was required to increase the relative difference ratio, and if above the upper bound of significance (+10%), the simulation was removed[4].

An example of the calculation for the maximum relative difference ratio is shown using the final selected simulations (1, 3, 5). At Point 1, the maximum peak discharge is Simulation 3, as the relative difference ratio is 4.2%, where Simulation 1 is only 1.2% higher and Simulation 5 is 2.1% lower. This maximum indicates at Simulation 3 is expected to dominate within the hydraulic model at Point 1. This simulation will also dominate at Point 3 and 4. Similarly, Simulation 1 will dominate for Point 2, and Simulation 5 will dominate at Point 5. With Figure 4.4, the maximum of highest relative difference ratios are indicated by the border of the cell coloured in light blue and filled with light blue dots.

In the selection of the final sub-set, it is noted that Simulation 2 and 4 have been eliminated. These simulations were removed as Simulation 2 and 4 has a significantly high relative difference ratio (>+10%) at Point 2 and Point 3 respectively. Simulation 1 and 5 could also be eliminated as Simulation 3 has all points within the chosen target range (±10%). These simulations however, have a peak discharge that is closer to the critical storm at Point 2 and Point 5 respectively (in this case they are the critical storm), whilst not impacting other points so they can be included in the sub-set.

Design Event Modelling Point Name	Simulation 1	Simulation 2	Simulation 3	Simulation 4	Simulation 5
Point 1	1.2%	0.0%	4.2%	-1.2%	-2.1%
Point 2	0.0%	11.5%	-7.5%	-12.3%	-14.2%
Point 3	-10.4%	-10.5%	0.0%	15.3%	-5.9%
Point 4	-8.4%	-8.9%	5.5%	0.0%	-1.5%
Point 5	-39.3%	-39.5%	-3.7%	-7.9%	0.0%

Figure 4.4 Example of the final matrix with all selected simulation and the maximum relative difference ratios highlighted.

4.4 Final sub-set and results matrix

The final sub-set of simulation are listed in Table 4.8. The matrices of all AEP from 20% to 0.05% are shown in Figure 4.5 to Figure 4.11 respectively. The following can be noted about the results:

- Whilst most AEP events required only 2 critical storms to represent all Design Event Modelling points, an additional storm was selected as it did not impact the other points.
- Preference was given to the critical storms that have a relative difference ratio greater than 0%. For example, ARFc 270 (TP7) in the 0.05% AEP was preferred over ARFd 270 (TP7) as SID001_10382 had a relative difference ratio of -5.2% for the latter. Noting that either event would have represented this AEP adequately.

[4] Noting there may be trade-off between being outside the bounds at one point to match at another.

Table 4.8 List of the sub-set of simulations of the hydraulic model

AEP	Grouping	Duration (minutes)	TP (1- 10)
20%	ARFc	180	6
	ARFc	270	5
	ARFe	720	5
10%	ARFc	180	4
	ARFd	360	7
	ARFe	540	10
5%	ARFc	180	8
	ARFe	540	9
2%	ARFc	120	8
	ARFc	270	7
	ARFe	360	6
1%	ARFc	120	8
	ARFc	270	7
	ARFe	360	4
0.1%	ARFc	120	1
	ARFc	270	7
	ARFe	360	10
0.05%	ARFc	120	1
	ARFc	270	7
	ARFe	360	10

	ARFc_180 (TP6)	ARFc_270 (TP5)	ARFd_270 (TP4)	ARFe_720 (TP5)
SID004_00814	0.0%	0.0%	-9.5%	-35.3%
SID010_01949	0.0%	-5.9%	-19.5%	-44.2%
SID001_10382	-7.1%	0.0%	-3.2%	-31.1%
SID001_08305	-10.4%	4.0%	0.0%	-25.0%
SID001_01506	-36.9%	-15.0%	-18.6%	0.0%

Figure 4.5 Results matrix for the 20% AEP

	ARFc_180 (TP4)	ARFc_180 (TP8)	ARFd_360 (TP7)	ARFe_540 (TP10)
SID004_00814	0.2%	0.0%	-14.6%	-25.6%
SID010_01949	0.0%	2.6%	-16.1%	-32.1%
SID001_10382	0.2%	0.0%	-5.1%	-17.9%
SID001_08305	-2.6%	-2.8%	0.0%	-12.5%
SID001_01506	-31.4%	-31.5%	-2.7%	0.0%

Figure 4.6 Results matrix for the 10% AEP

	ARFc_180 (TP4)	ARFc_180 (TP8)	ARFd_360 (TP7)	ARFe_540 (TP9)
SID004_00814	-2.1%	0.0%	-16.6%	-10.3%
SID010_01949	-5.4%	0.0%	-17.1%	-15.6%
SID001_10382	0.0%	0.9%	-7.4%	-6.6%
SID001_08305	2.0%	2.7%	0.0%	-1.3%
SID001_01506	-21.0%	-20.9%	3.8%	0.0%

Figure 4.7 Results matrix for the 5% AEP

	ARFc_120 (TP8)	ARFc_270 (TP7)	ARFd_270 (TP7)	ARFe_360 (TP6)
SID004_00814	-10.0%	0.0%	-3.8%	-20.6%
SID010_01949	0.0%	-1.2%	-4.9%	-22.8%
SID001_10382	-18.6%	0.0%	-3.7%	-18.7%
SID001_08305	-21.7%	4.0%	0.0%	-12.8%
SID001_01506	-45.4%	-5.4%	-8.5%	0.0%

Figure 4.8 Results matrix for the 2% AEP

	ARFc_120 (TP8)	ARFc_270 (TP7)	ARFd_270 (TP7)	ARFe_360 (TP4)
SID004_00814	-9.7%	0.0%	-4.3%	-12.9%
SID010_01949	0.0%	-2.3%	-6.6%	-14.4%
SID001_10382	-18.2%	0.0%	-4.2%	-11.9%
SID001_08305	-21.1%	4.4%	0.0%	-8.0%
SID001_01506	-47.7%	-5.3%	-8.5%	0.0%

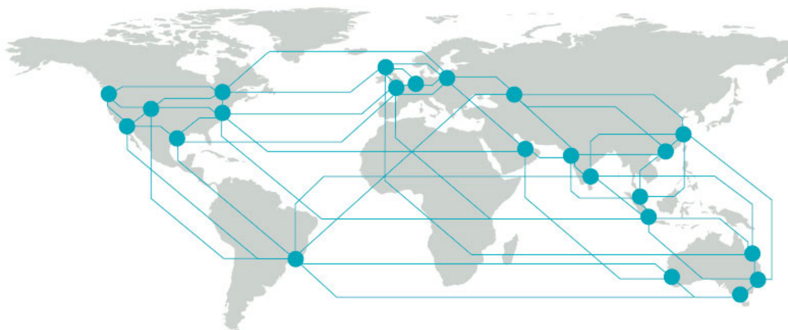
Figure 4.9 Results matrix for the 1% AEP

	ARFc_120 (TP1)	ARFc_270 (TP7)	ARFd_270 (TP7)	ARFe_360 (TP10)
SID004_00814	-3.5%	0.0%	-5.0%	-5.4%
SID010_01949	0.0%	-7.2%	-11.9%	-13.5%
SID001_10382	-11.4%	0.0%	-5.0%	-5.3%
SID001_08305	-10.5%	5.2%	0.0%	-1.4%
SID001_01506	-40.9%	-3.9%	-7.8%	0.0%

Figure 4.10 Results matrix for the 0.1% AEP

	ARFc_120 (TP1)	ARFc_120 (TP8)	ARFc_270 (TP7)	ARFd_270 (TP7)	ARFe_360 (TP10)
SID004_00814	1.2%	0.0%	4.2%	-1.2%	-2.1%
SID010_01949	0.0%	-2.7%	-7.5%	-12.3%	-14.2%
SID001_10382	-10.4%	-10.5%	0.0%	-5.3%	-5.9%
SID001_08305	-8.4%	-8.9%	5.5%	0.0%	-1.5%
SID001_01506	-39.3%	-39.5%	-3.7%	-7.9%	0.0%

Figure 4.11 Results matrix for the 0.05% AEP



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