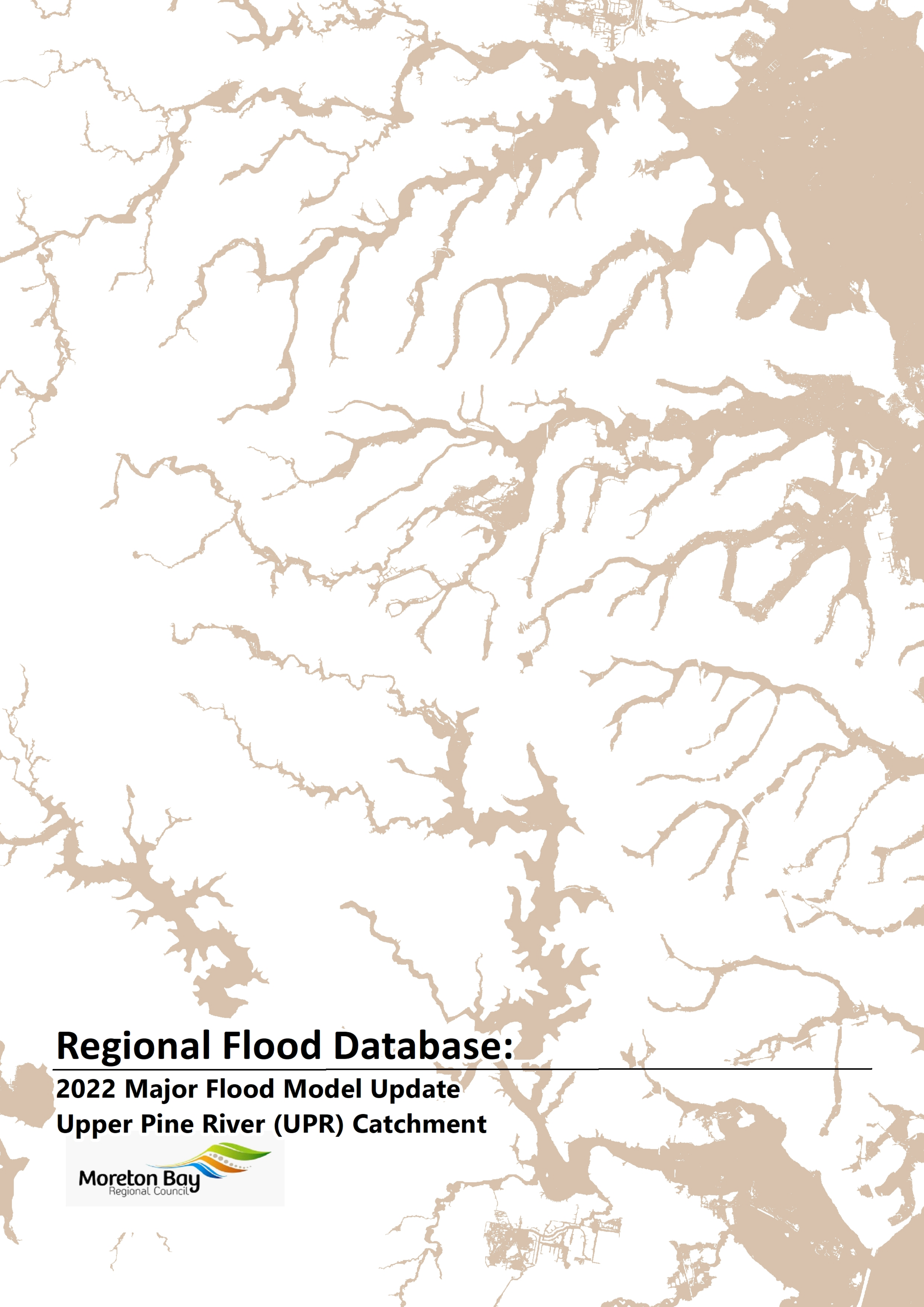

# Regional Flood Database:

## 2022 Major Flood Model Update
## Upper Pine River (UPR) Catchment

Moreton Bay Regional Council

# Regional Flood Database: 2022 Major Flood Model Update - Upper Pine River (UPR) Catchment - Stage 4 and 5 Final Report

| | |
|---|---|
| Customer | Moreton Bay Regional Council |
| Project | A11567 |
| Deliverable | 006 |
| Version | 02 |
| | 4 September 2023 |

# Document Control

## Document Identification

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| Title | Regional Flood Database: 2022 Major Flood Model Update - Upper Pine River (UPR) Catchment - Stage 4 and 5 Final Report |
| Project No | A11567 |
| Deliverable No | 006 |
| Version No | 02 |
| Version Date | 4 September 2023 |
| Customer | Moreton Bay Regional Council |
| Customer Contact | Hester van Zijl |
| Classification | BMT (OFFICIAL) |
| Synopsis | This report summarises the tasks of Stage 4 and Stage 5 of the RFD 2022 Update in the Upper Pine River catchment including model updates, model calibration, the development of HEH models and design event modelling. |

| | |
|---|---|
| Author | Blair Filer, Charmaine Machikiti, Barry Rodgers, Luana Stefanon |
| Reviewed By | Anne Kolega |
| Project Manager | Barry Rodgers |

## Amendment Record

The Amendment Record below records the history and issue status of this document.

| Version | Version Date | Distribution | Record |
|---|---|---|---|
| 00 | 25 July 2023 | Moreton Bay Regional Council | Initial Draft Report |
| 01 | 24 August 2023 | Moreton Bay Regional Council | Draft Report |
| 02 | 4 September 2023 | Moreton Bay Regional Council | Final Report |

# 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 Upper Pine River 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 UPR 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 Blockage Factors
- Annex F Technical Note: Upper Pine River 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 UPR 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.

# Contents

# 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 (UPR) and Lower Pine River in combination with Hays Inlet (LPH).

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 UPR minor basin for Stage 4 and Stage 5 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 Upper Pine River (UPR) hydrologic and hydraulic models were initially developed as part of the Stage 2, Regional Flood Database[3]. In 2014, the UPR 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 Floodplain Database, Hydrologic and Hydraulic modelling Report: Upper Pine River (UPR)
[4] BMT (2015) Regional Floodplain Database 2014 Model Maintenance Report, Upper Pine River (UPR)
[5] ARUP (2021) Regional Flood Database ARR 2019 Pilot Study
[6] AECOM (2020) 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 UPR 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[9] 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) and to cover additional upstream areas in the flood modelling and mapping.

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

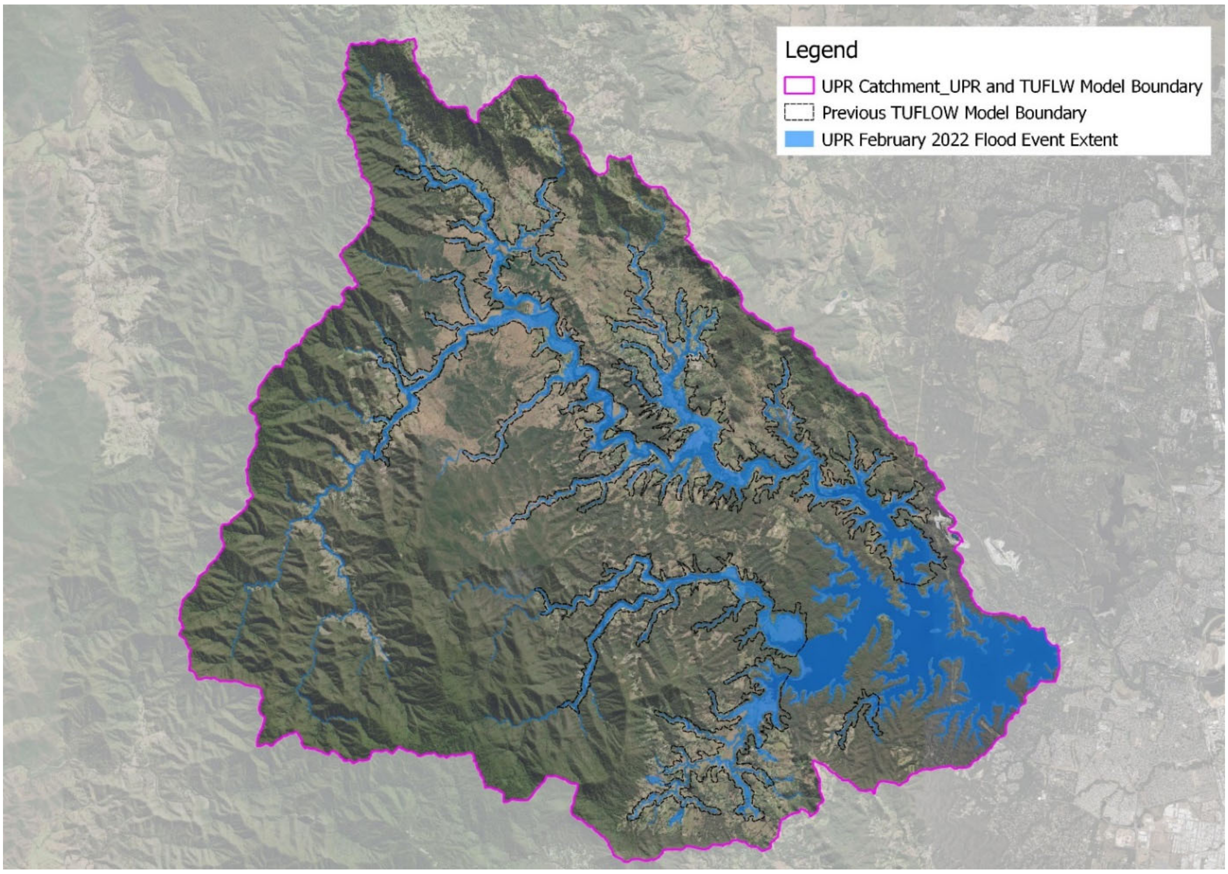



Figure 3.1 TUFLOW Model Extent

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<br>10m with SGS used for initial calibration runs and 5m without SGS for final calibration runs |
| Model Extent | 2d_code boundary expanded to include local flows |
| Terrain | 2019 LiDAR<br>Dam DEM<br>Heritage Crescent Development DEM<br>Watercourses enforced by updated 2d_zsh streamlines |
| Structures | Updated 1D stormwater network and culverts based on data provided by Council.<br>Additional road centrelines by using the 2d_zsh new roads layer<br>Additional guard rail and fauna fence information by using the 2d_lfcsh guard rails and fauna fences |

| Change | Details |
|---|---|
| North Pine Dam Representation | North Pine Dam used to be modelled using 1D now modelled using 2D |
| Land Use | 2019 Pervious-Impervious Raster, developed as part of Stage 2[10] for vegetation density.<br>2d_mat files to enforce concrete, bitumen, buildings and waterways |

[10] 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 UPR catchment has been calibrated to the historic events January 2011 and February 2022. It was then validated to the event of March 2017. Of these three events, the February 2022 was the most significant across the UPR catchment and the 2017 was notably smaller. Table 4.1 provides a summary of the events modelled.

Table 4.1 Modelled Events: UPR

| Event | Model Start | Model End | Simulation Period (h) | Accumulated Rainfall during the event at Dayboro WWTP AL |
|---|---|---|---|---|
| January 2011 | 09/1//2011 00:00 | 12/1/2011 18:00 | 90 | 550mm |
| March 2017 | 29/3/2017 12:00 | 2/4/2017 16:00 | 100 | 280mm |
| February 2022 | 23/02/2022 06:00 | 28/2/2022 06:00 | 120 | 900mm |

### 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.

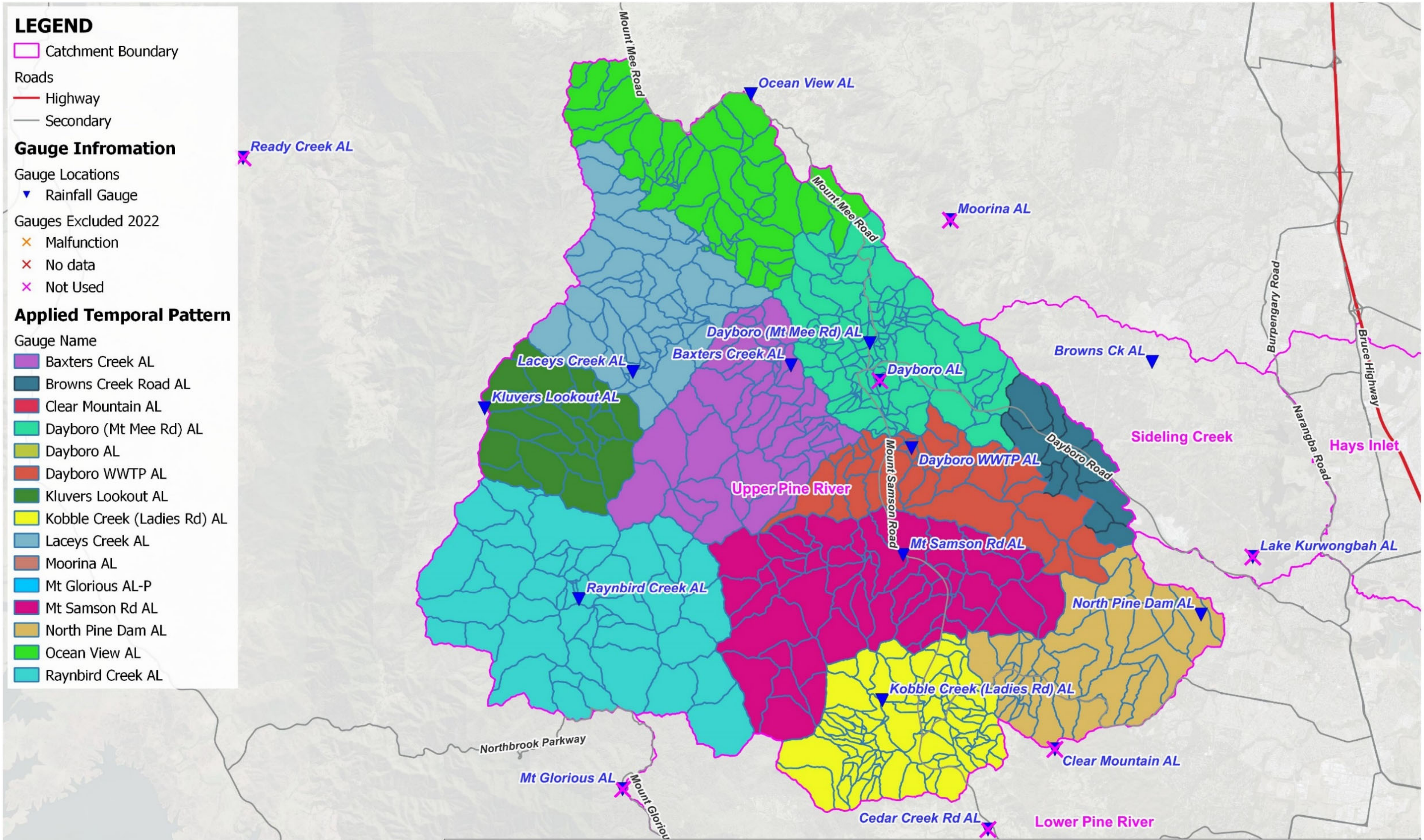
Key points regarding applications of rainfall gauges are:

- Mt Glorious AL-P was excluded due to the direction of the storm, North Pine Dam AL rainfall total was eliminated as it was much lower than surrounding gauges and affected the dam outflow in the hydraulic model calibration. No external daily gauges were applied as matching at stream gauges was achieved.
- Council flagged Raynbird Ck AL as malfunctioning during the event, however the gauge rainfall totals was consistence with surrounding gauges and the rain bands experienced throughout the event, hence it was included.
- Kobble Creek (Ladies Rd) AL was not applied to Kobble Creek (South Branch) like the process undertaken in the 2017 event. This was due to the intense rainfall band on 27 February not occurring in the upstream area of Kobble Creek catchment to the same extent as Mt Samson Creek and Cedar Creek.

- Raynbird Creek AL was extended east to the upstream Kobble Creek (North Branch) and Kobble Creek (South Branch) to meet the initial peaks at Kobble Creek AL. The use of Mt Samson AL throughout Kobble Creek matched the recorded peaks on 26 January better however largely overestimated the peak on 27 January. A trade off of the difference between matching the peaks on 26 and 27 January had to be made.
- Ocean View AL and Laceys Creek AL temporal pattern was applied to Pine Creek and Upper North Pine River due to the absence of other gauges in the area. Different temporal patterns were also trailed in the area however did not change the outcome significantly.
- Dayboro (Mt Mee) AL temporal pattern was used for all Torrens Creek. Using Moorina AL temporal pattern at the top of Torren Creek similar to the 2017 event underestimated peaks.

Table 4.2 Rain Gauges Applied – February 2022

| Gauge Name | Gauge ID | Temporal Pattern | Depth | Total Recorded Rainfall (mm) |
|---|---|---|---|---|
| Baxters Creek AL | 540189 | ✓ | ✓ | 725 |
| Browns Creek Road AL | 540411 | ✓ | ✓ | 868 |
| Cedar Creek Rd AL | 540444 | | ✓ | 986 |
| Clear Mountain AL | 540418 | | ✓ | 845 |
| Dayboro (Mt Mee Rd) AL | 540628 | ✓ | ✓ | 877 |
| Dayboro WWTP AL | 540484 | ✓ | ✓ | 783 |
| Kluvers Lookout AL | 540168 | ✓ | ✓ | 743 |
| Kobble Creek (Ladies Rd) AL | 540656 | ✓ | ✓ | 880 |
| Laceys Creek AL | 540409 | ✓ | ✓ | 668 |
| Lake Kurwongbah AL | 540204 | | ✓ | 1012 |
| Moorina AL | 540358 | | ✓ | 834 |
| Mt Samson Rd AL | 540447 | ✓ | ✓ | 829 |
| Ocean View AL | 540634 | ✓ | ✓ | 901 |
| Raynbird Creek AL | 540545 | ✓ | ✓ | 688 |




Title:

**February 2022 event temporal pattern applied in model**

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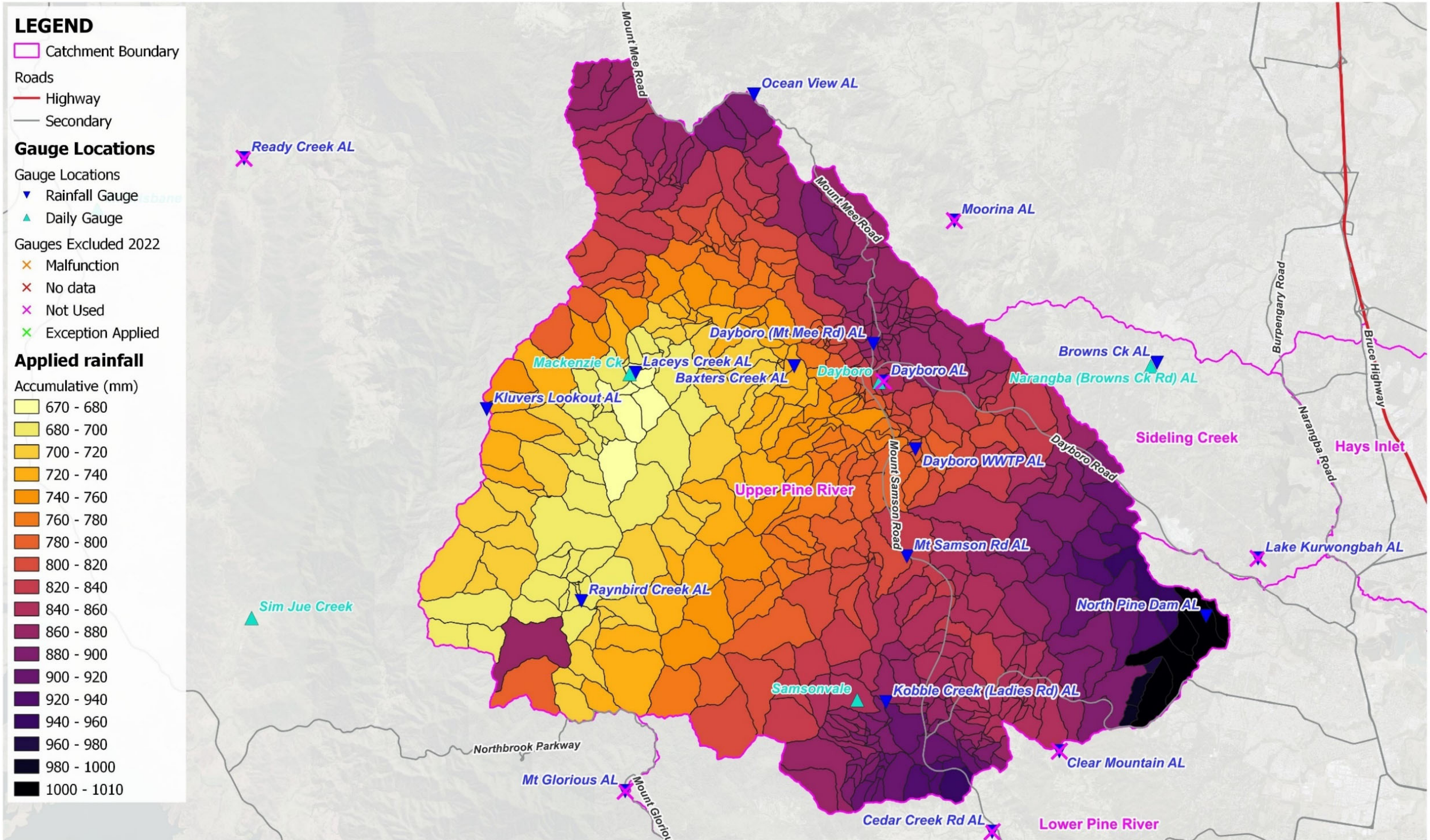


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**February 2022 event total rainfall applied in model**

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*January 2011 Event*

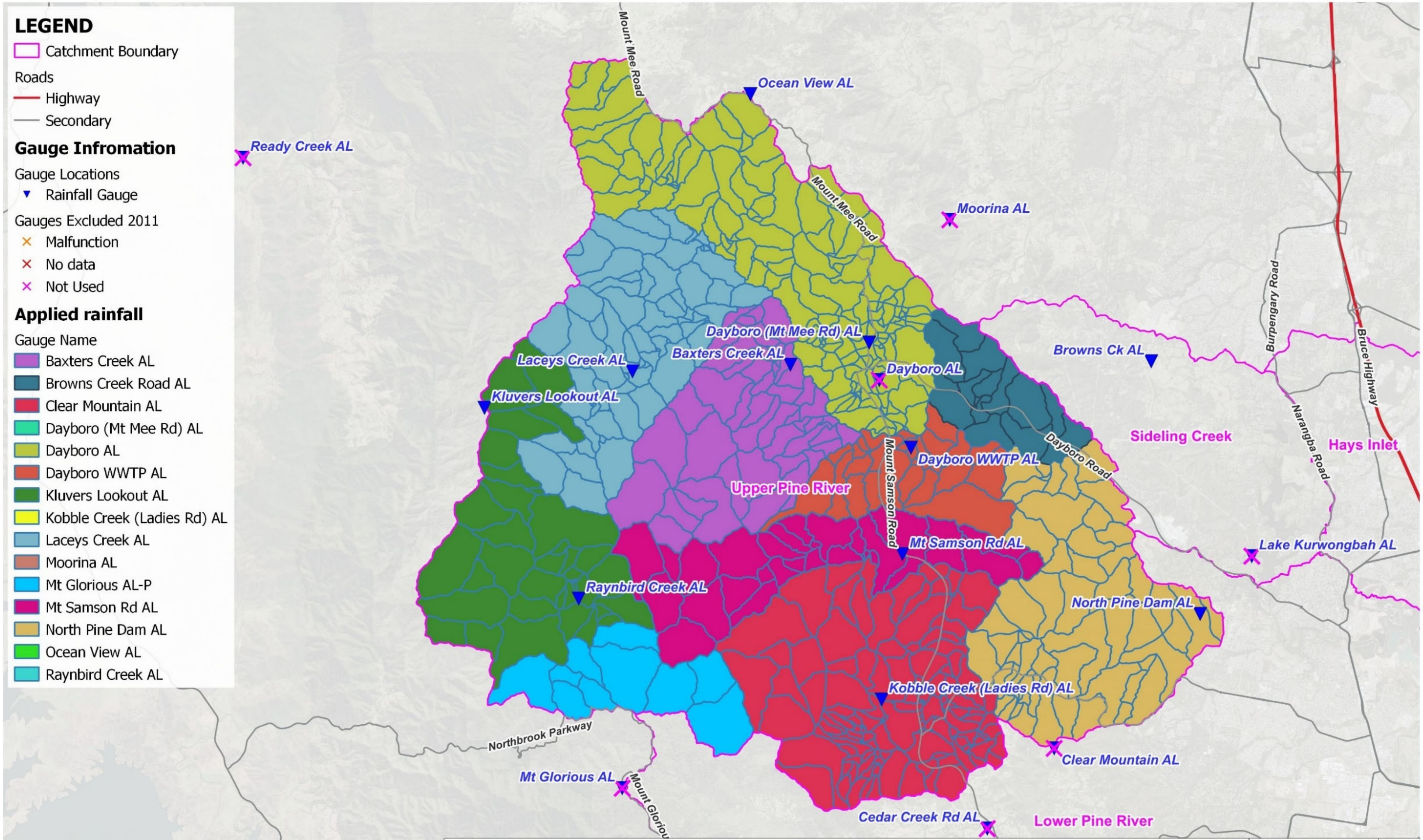
Rainfall loss values of 10mm initial loss and 1.0 mm/h continuing loss were adopted for the 2011 event validation. Table 4.3 lists the gauges used in the event. Figure 4.3 the temporal pattern applied for each sub-catchment and Figure 4.4 shows the distribution of rainfall totals applied in the WBNM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

Key points regarding application of rainfall gauges:

- External daily gauges on the western side of the catchment were also applied to try and reduce rainfall totals at upper Laceys Creek (before the confluence to Raynbird Creek). It is suspected that the initial peak is too high due to the rainfall not captured accurately in this part of the catchment.
- Clear Mountain AL temporal pattern was applied to Mt Samson Creek. This gauge's temporal pattern was also applied to the southern portion of Kobble Creek, most notably the Kobble Creek (South Branch) to achieve the initial multiple peaks at Kobble Creek AL.
- Mt Glorious AL temporal pattern was applied to the top of Raynbird Creek to minimise the initial peak at Baxter Creek and provided at better shape of the peak on 11 January. The temporal pattern of this gauge was also applied to top portions of Kobble Creek (South Branch) to aid the calibration at Kobble Creek AL. Rainfall totals were not used for Mt Glorious AL due to the direction of the storm and the large rainfall totals at Mt Glorious.
- Regarding the above two points, the application of temporal patterns in Kobble Creek was a trade-off between achieving the initial peaks or the trough before the large peak on 11 January. BMT chose to achieve the initial peaks.
- Dayboro AL temporal pattern was applied to Pine Creek and upper North Pine River due to the absence of other gauges in the area. Mt Mee AL-P rainfall totals and external daily gauges were used to approximate rainfall in these catchments. Moorina AL and Mt Mee AL-P were also trialled in these catchments with lesser success at achieving a match at Baxters Creek.

## Table 4.3 Rain Gauges Applied – January 2011

| Gauge Name | Gauge ID | Temporal Pattern | Depth | Total Recorded Rainfall (mm) |
|---|---|---|---|---|
| Baxters Creek AL | 540189 | ✓ | ✓ | 501 |
| Browns Creek Road AL | 540411 | ✓ | ✓ | 340 |
| Cedar Creek Rd AL | 540444 | | ✓ | 383 |
| Clear Mountain AL | 540418 | ✓ | ✓ | 285 |
| Dayboro WWTP AL | 540484 | ✓ | ✓ | 536 |
| Kluvers Lookout AL | 540168 | ✓ | ✓ | 487 |
| Laceys Creek AL | 540409 | ✓ | ✓ | 529 |
| Lake Kurwongbah AL | 540204 | | ✓ | 174 |
| Moorina AL | 540358 | | ✓ | 575 |
| Mt Mee AL-P | 540185 | ✓ | ✓ | 568 |
| Mt Samson Rd AL | 540447 | ✓ | ✓ | 485 |
| North Pine Dam AL | 540202 | ✓ | ✓ | 207 |

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**January 2011 event temporal pattern applied in model**

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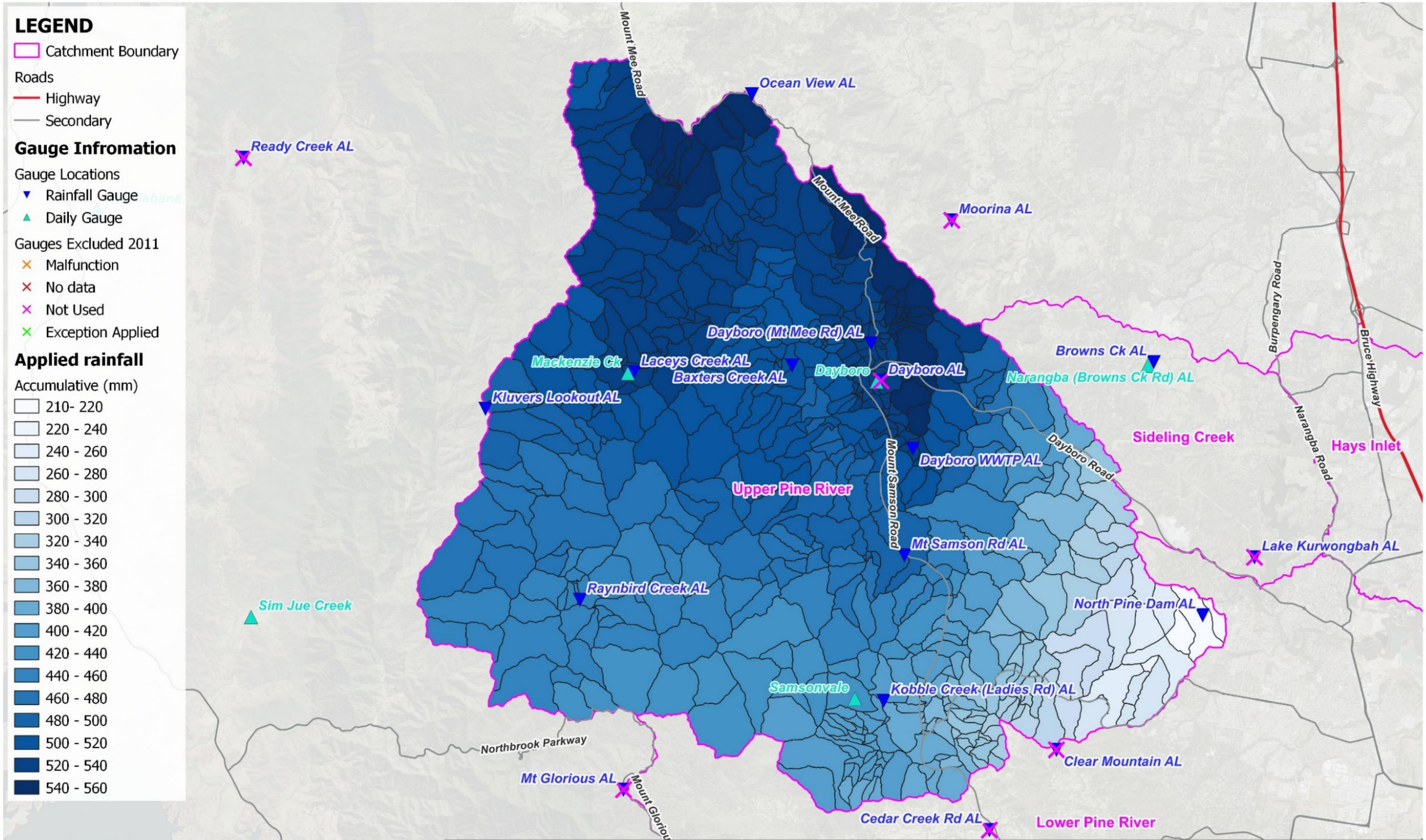


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**January 2011 event total rainfall applied in model**

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*March 2017 Event*

Rainfall loss values of 70 mm initial loss and 5.0 mm/h continuing loss were adopted for the 2017 event calibration. Table 4.4 lists the gauges used in the event. Table 4.5 the temporal pattern applied for each sub-catchment and Table 4.6 shows the distribution of rainfall totals applied in the WBNM model.

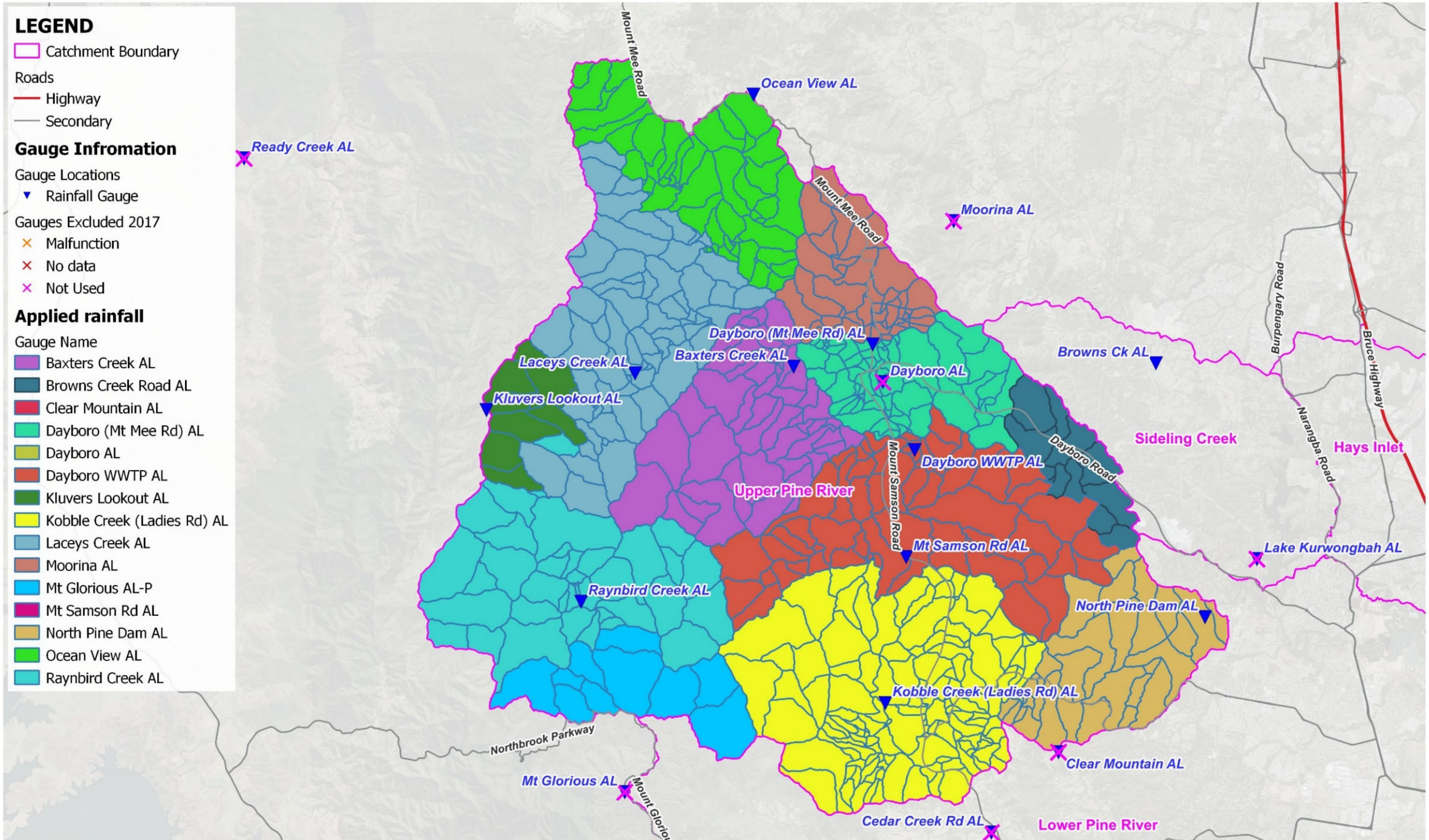
Key points regarding application of rainfall gauges:

- It is suspected that very intense rainfall occurred at the upstream area of Pine Creek and Torrens Creek due to the orthographic effects of the mountains, as well as within Raynbird Creek between Baxters Creek and Kobble Creek. It is noted that radar data shows an intense rainfall band affecting these areas. Hence, the rainfall in these individual catchments was calculated separately using all available gauges.
- Rainfall totals in other areas of the model were calculated excluding Ocean View AL, and Raynbird AL. Similar to 2011, external daily gauges on the western side of the catchment and Mt Mee AL-P were applied to try and reduced rainfall totals at upper Laceys Creek (before the confluence to Raynbird Creek) and upper North Pine River (before the confluence to Pine Creek). Inclusion of Ocean View AL, and Raynbird AL increase discharge at Baxters Ck AL by approximately 200m3/s (approximately double) for the first peak.
- The ridgeline gauge of Kluvers Outlook AL was considered of being too high however did not affect the overall rainfall total calculation.
- Mt Glorious AL was applied in a similar manner to the 2011 event. The rainfall total was excluded as it affected the first peak.
- Due to Mt Samson Rd AL malfunctioning during the event, Kobble Creek (Ladies Rd) AL temporal pattern was extended north to the southern portion of Kobble Creek, and Dayboro WWTP AL extended south to the northern portion. Raynbird Creek AL temporal pattern was extended east to the upstream Kobble Creek (North Branch).
- Dayboro (Mt Mee) AL and Moorina AL temporal pattern was used for Torrens Creek and provided a better match at Dayboro (Mt Mee) AL due to the direction of the storm. This is different to the 2022 event where only Dayboro (Mt Mee) was applied. Dayboro AL temporal pattern was similar to Dayboro (Mt Mee) AL, hence not used.
- Ocean View AL and Laceys Creek temporal pattern was applied to Pine Creek and upper North Pine River due to the absence of other gauges in the area. This is similar to the 2022 event.

### Table 4.4 Rain Gauges Applied – March 2017

| Gauge Name | Gauge ID | Temporal Pattern | Depth | Total Recorded Rainfall (mm) |
|---|---|---|---|---|
| Baxters Creek AL | 540189 | ✓ | ✓ | 241 |
| Browns Creek Road AL | 540411 | ✓ | ✓ | 181 |
| Cedar Creek Rd AL | 540444 | | ✓ | 222 |
| Clear Mountain AL | 540418 | | ✓ | 134 |
| Dayboro (Mt Mee Rd) AL | 540628 | ✓ | ✓ | 277 |
| Dayboro AL | 540410 | | ✓ | 278 |
| Dayboro WWTP AL | 540484 | ✓ | ✓ | 264 |

| Gauge Name | Gauge ID | Temporal Pattern | Depth | Total Recorded Rainfall (mm) |
|---|---|---|---|---|
| Kluvers Lookout AL | 540168 | ✓ | ✓ | 234 |
| Kobble Creek (Ladies Rd) AL | 540656 | ✓ | ✓ | 229 |
| Laceys Creek AL | 540409 | ✓ | ✓ | 242 |
| Lake Kurwongbah AL | 540204 | | ✓ | 193 |
| Moorina AL | 540358 | | ✓ | 249 |
| Mt Mee AL-P | 540185 | ✓ | ✓ | 241 |
| North Pine Dam AL | 540202 | ✓ | ✓ | 119 |
| Ocean View AL | 540202 | ✓ | ✓ | 349 |
| Raynbird Creek AL | 540545 | ✓ | ✓ | 292 |
| Ready Creek AL | 140633B | | ✓ | 125 |

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**March 2017 event temporal pattern applied in model**

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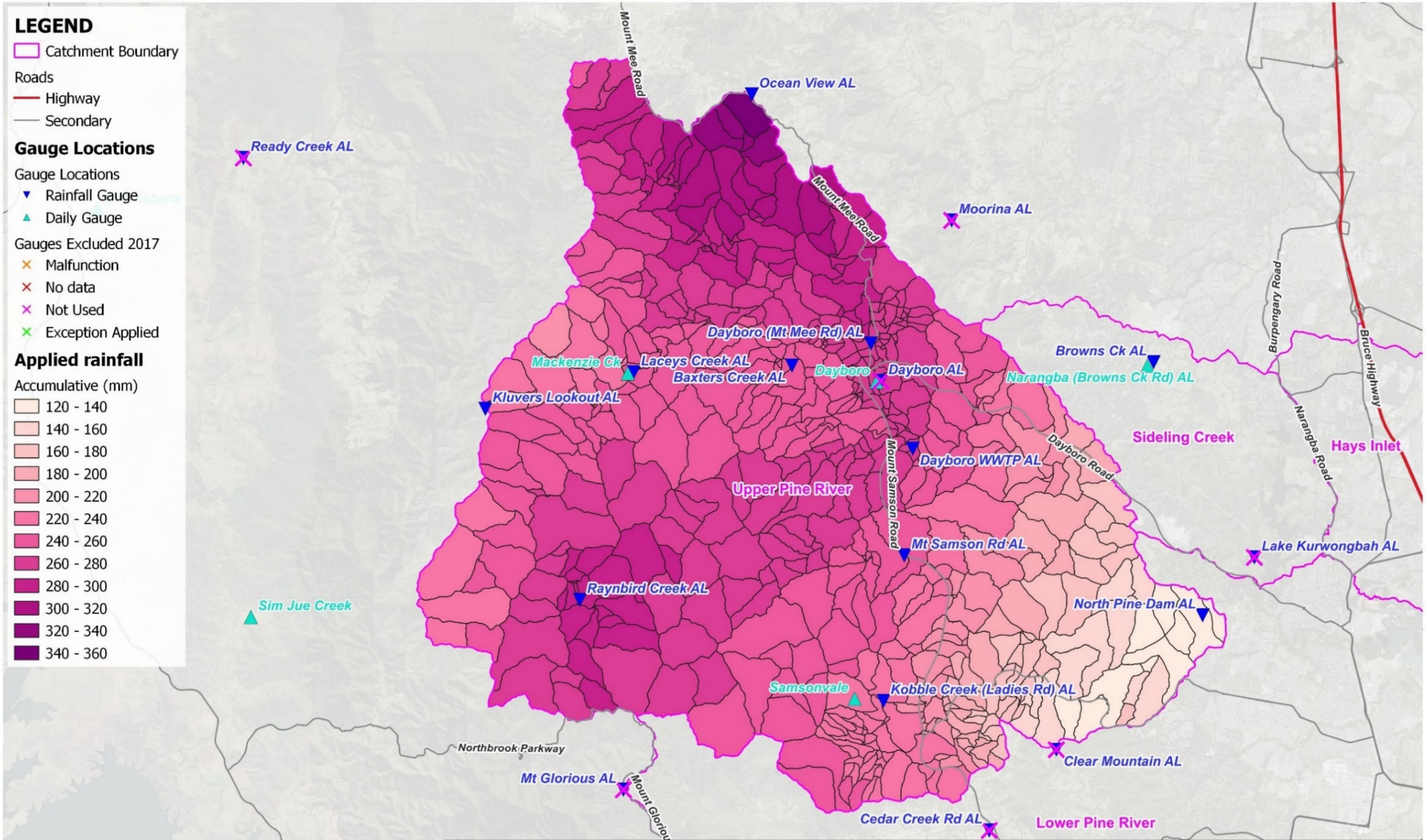


Title:
**March 2017 event total rainfall applied in model**

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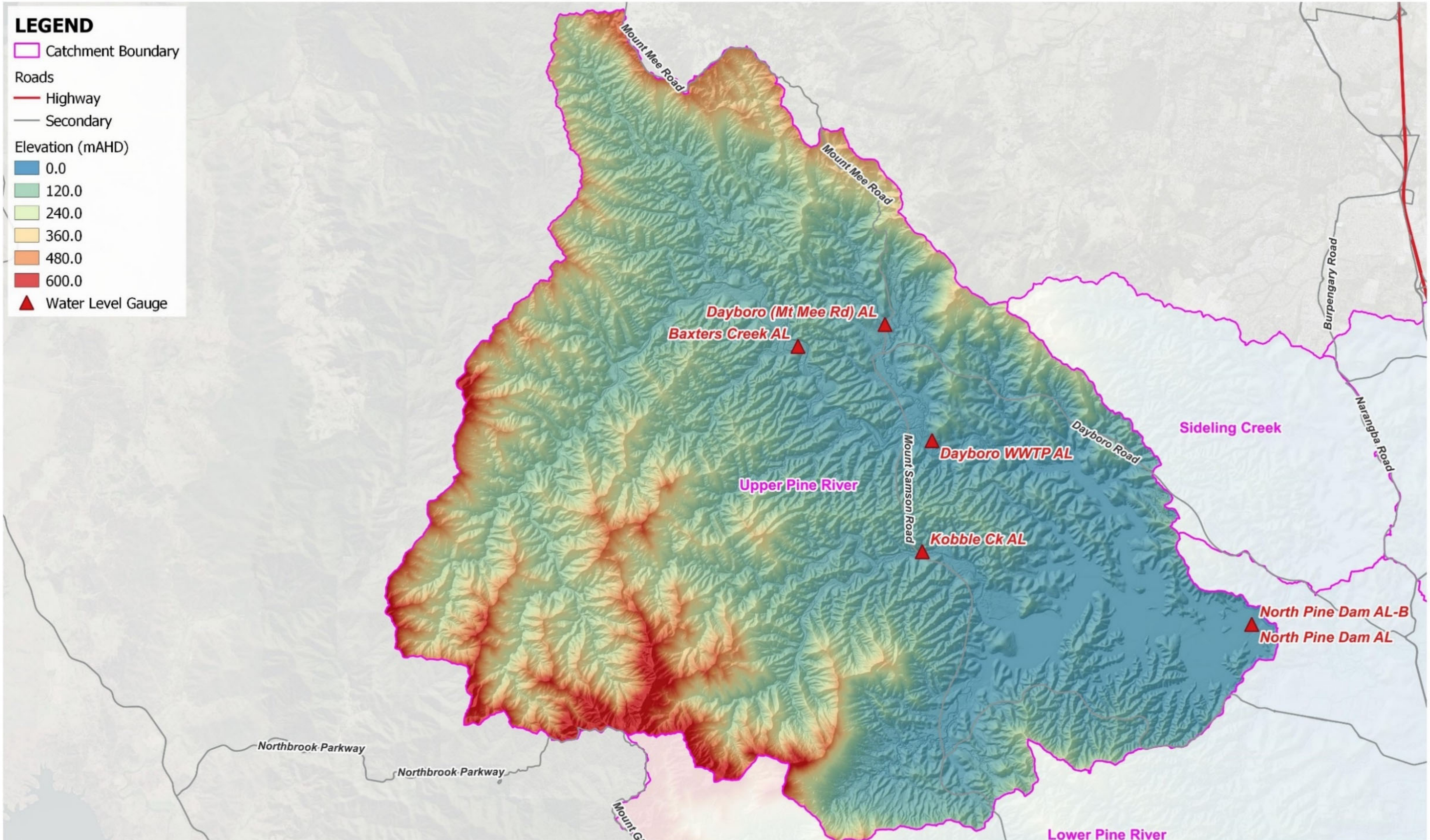
### Stream Gauges

Stream gauges that recorded event water levels are listed in Table 4.5 Data for these gauges was provided by Council. Stream gauges are used in the calibration by plotting the recorded level against the modelled levels and assessing the match to flood peak, timing, volume and hydrograph shape.

Table 4.5 Available Stream Gauges

| Gauge Name | Gauge ID | Watercourse | 2011 | 2017 | 2022 |
|---|---|---|---|---|---|
| Kobble Creek Alert | 540656 | Mt Samson Creek | ✓ | | ✓ |
| Baxters Creek Alert | 540189 | North Pine River | ✓ | ✓ | ✓ |
| Dayboro (Mt Mee Road) Alert | 540628 | Terrors Creek | | ✓ | ✓ |
| Dayboro WWTP Alert | 540484 | North Pine River | Gauge Failed | ✓ | ✓ |
| North Pine Dam Alert | 540202 | Lake Samsonvale | ✓ | ✓ | ✓ |




| Title: Stream gauges in UPR calibration | Figure: 4-7 | Rev: A |
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**Surveyed Flood Marks**

For the UPR catchment, 35, 16 and 52 flood marks were surveyed following the January 2011, March 2017 and February 2022 events, respectively.

### 4.1.3 TUFLOW

**Model Changes**

There were significant changes applied to the model for the 2011, 2017 and 2022 events. Different outflows and initial water levels were applied to the model for each event.

## 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 4.8. Figure 2.1, Annex C, shows the POIs of interest within the UPR catchment, and the HEH points selected for this study. Specific details regarding the steps involved in the implementation of the HEH methodology within the UPR catchment are summarised in Table 4.6. For comprehensive details of HEH model methodology, refer to Annex B, which includes a Technical Note on the HEH Modelling Methodology.

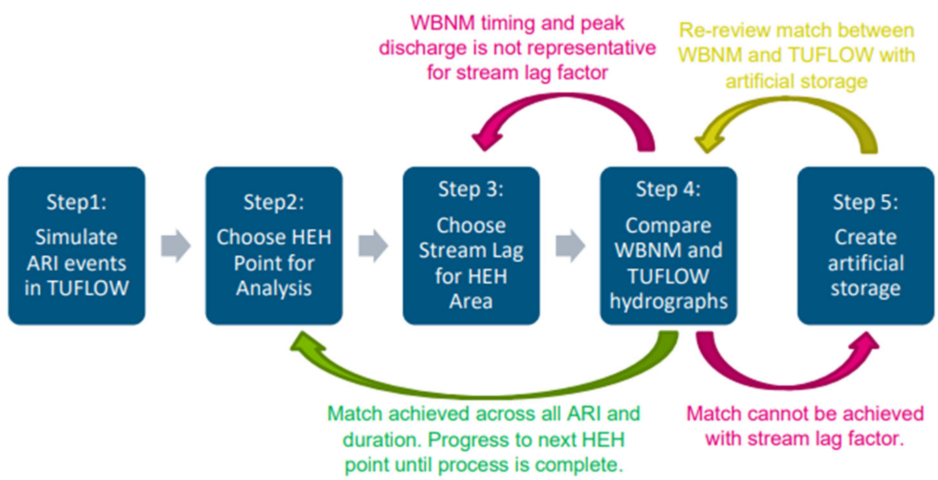



Figure 4.8 Flow chart for the HEH model methodology

Table 4.6 Further Details when Implementing HEH Model Development

| Step | Comment |
|---|---|
| 1 | The following ARI events and durations were simulated through the TUFLOW model[11]:<br>• ARI events– 5-year, 20-year, 100-year, 2000-year<br>• 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:<br>• The WBNM outputs were interpolated to match the TUFLOW output interval of 5-minutes.<br>• WBNM total flows at confluences were combined.<br>• At culvert locations, where TUFLOW contains both flow in 1D and 2D domains, the 1D and 2D flows were combined.<br>• 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:<br>• 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.<br>• 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.<br>• The artificial storage was applied using either of the two methods below:<br>  - 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.<br>  - 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. |
| 6 | Two different rating curves (provided by SEQWater) were adopted in the HEH modelling to represent the operating rules of North Pine Dam (the most downstream catchment of the UPR model).<br>• The existing conditions used the Revision 11 of the operating.<br>• The future conditions used the Revision 9 of the operating rules.<br>The hydrographs for both scenarios are presented in Appendix D. |

[11] 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.

## 4.3 TUFLOW Hydraulic Model

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

The downstream boundary of the UPR hydraulic model was located at the embankment of North Pine Dam, where the rating curve derived by SEQWater for North Pine Dam was applied as downstream boundary condition.

The SEQWater rating curves adopted in the present study in liaison with Council are shown in Figure 4.9. Revision 11 rating curve and initial water level of 36 mAHD were applied to the existing condition simulations. Revision 9 rating curve and initial water level of 38.6 mAHD were applied to the future condition simulations.

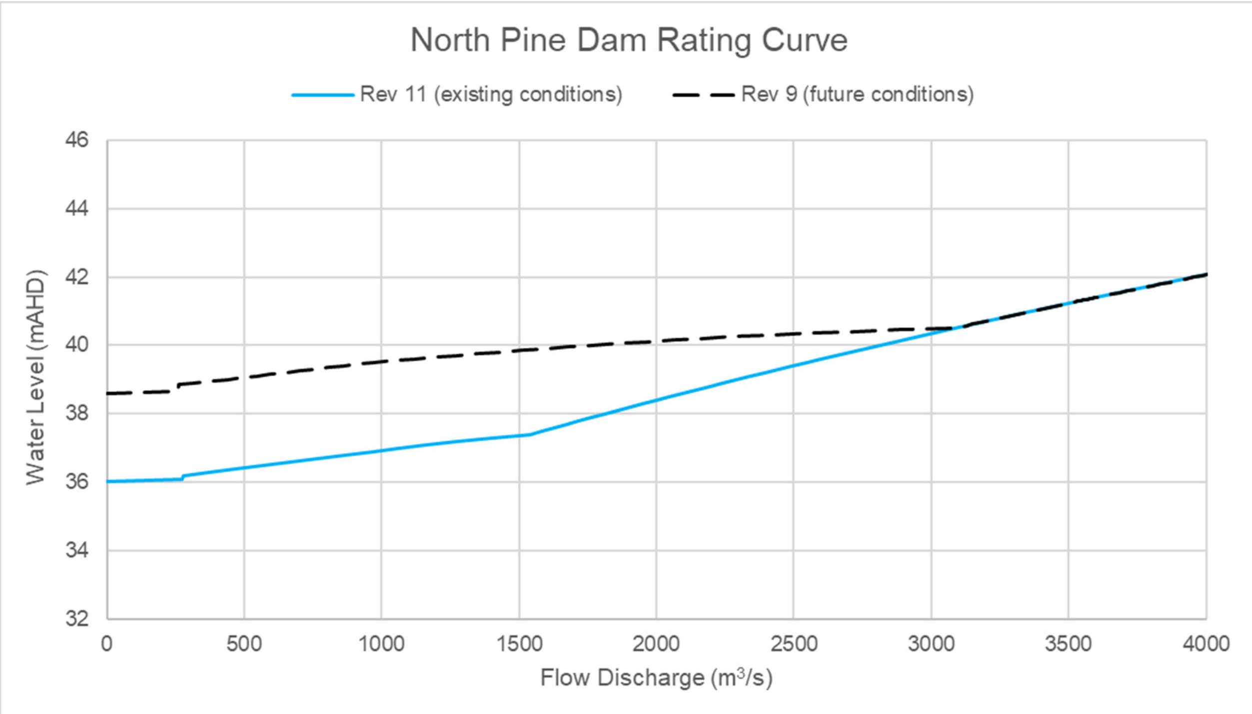



Figure 4.9 SEQWater Rating Curve at North Pine Dam

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

- The unblocked scenario included no blockage applied to culverts, trunk stormwater pipes and pits, and bridges.
- The blocked scenario was setup as follows:
  - Either a blockage factor or a modified inlet energy loss was applied to culverts and trunk stormwater pipes in accordance with the methodology adopted by MBRC and outlined in the “Regional Flood Database ARR2019 Pilot Study” report (ARUP, 2021).
  - Blockage factors were applied to bridges in accordance with the methodology adopted by MBRC and outlined in the “Regional Flood Database ARR2019 Pilot Study” report (ARUP, 2021).
  - A 100% blockage factor was applied to trunk stormwater pits in accordance with the methodology adopted by MBRC and described in the “Regional Flood Database ARR2019 Pilot Study” report (ARUP, 2021) and “Queensland Urban Drainage Manual” (QUDM, 4th Edition).

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%).
- 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 in order to classify the culverts in 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 (RAM) 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.

Annex E provides a summary of the modelled blockage for culverts, trunk stormwater pipes and bridges in the Upper Pine River catchment.

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: Upper Pine River Design Event Hydrology Modelling and Results provided in Annex F.

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 4.7. 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 4.7.

Table 4.7 Summary of Design Event Critical Storms and Scenarios

| AEP | Bucket | Duration and 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% | ARFb | 120 (TP6) | ✓ | ✓ | ✓ | | ✓ | |
| | ARFf | 360 (TP3) | ✓ | ✓ | ✓ | | ✓ | |
| 0.1% | ARFb | 120 (TP6) | ✓ | ✓ | ✓ | | ✓ | |
| | ARFf | 360 (TP3) | ✓ | ✓ | ✓ | | ✓ | |
| 1% | ARFb | 120 (TP6) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | ARFa | 180 (TP8) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | ARFd | 270 (TP7) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| | ARFd | 360 (TP9) | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| 2% | ARFa | 120 (TP6) | ✓ | ✓ | ✓ | | ✓ | |
| | ARFd | 360 (TP9) | ✓ | ✓ | ✓ | | ✓ | |
| 5% | ARFa | 360 (TP2) | ✓ | ✓ | ✓ | | ✓ | |
| | ARFd | 180 (TP8) | ✓ | ✓ | ✓ | | ✓ | |
| 10% | ARFd | 180 (TP8) | ✓ | ✓ | ✓ | | | |
| | ARFa | 180 (TP1) | ✓ | ✓ | ✓ | | | |
| | ARFi | 1080 (TP19) | ✓ | ✓ | ✓ | | | |
| 20% | ARFc | 180 (TP3) | ✓ | ✓ | ✓ | | | |
| | ARFc | 270 (TP1) | ✓ | ✓ | ✓ | | | |
| | ARFi | 1080 (TP17) | ✓ | ✓ | ✓ | | | |

# 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, the 2011 calibration event, and the 2017 validation event.

Overall, the calibration and validation of the UPR catchment to historical events is considered satisfactory. A very good match in hydrograph, peak, shape, and timing is achieved at most gauges in all three events. The calibration for all events was achieved using a consistent set of Manning's n roughness values. It is recommended that this same set of values is used for design flood modelling. The model also shows good agreement to the recorded flood marks for all events with a slight underprediction in the 2011 event, and a slight overprediction in the 2017 and 2022.

## 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 UPR catchment are summarised in Table 4.1, Annex C. 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.

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

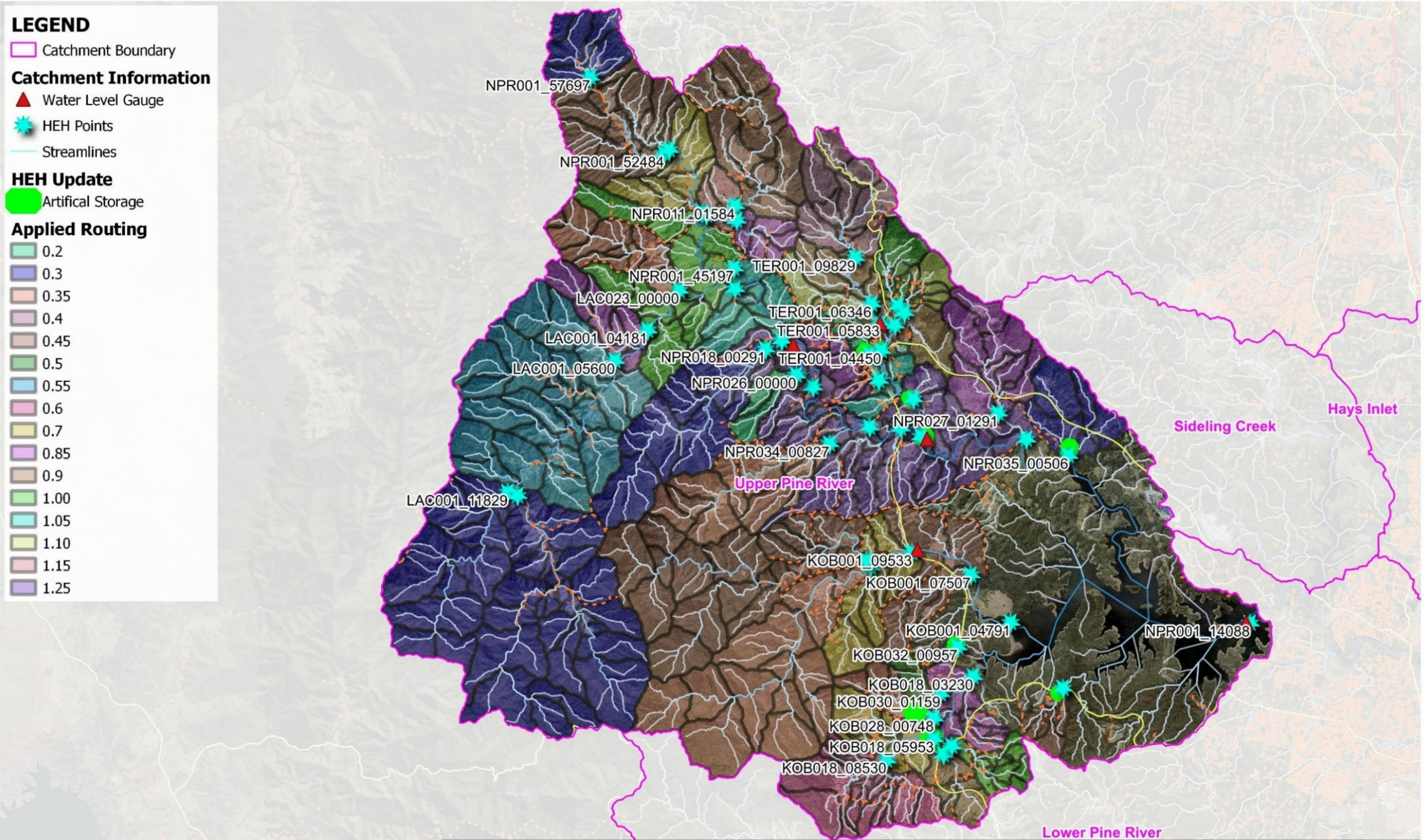
- The majority of HEH points have final scores that are considered either 'good' or 'excellent' with most of the HEH scores considered 'excellent'. All scores are within the desired range (Annex C) except for the anomalies summarised in Table 5.1.

Table 5.1 Anomalies in HEH results

| HEH Point | Anomaly Description |
|---|---|
| TER010_02189 | Breakout flow in the TUFLOW results from TER001_04450 in the 100-year and 2000-year ARI resulting in a higher score as shown in Figure 4.1, Annex C. |
| NPR056_01146 | Non uniform raising and falling shape due to the overtopping of the upstream road crossing. Figure 4.2, Annex C, and the provided plots show that the HEH model mostly achieves the shape. |
| NPR026_00000 | The influence by backwater from the main creek creating double peaks in the TUFLOW, as shown in Figure 4.3, Annex C. In most cases a negative peak is also experienced. |
| KOB028_00748 | The outlet of the real detention basins does not align with the sub-catchment for the 'KOB028_00748' HEH Point. This affects the storage calculations at these points as there are double peaks in the TUFLOW results which cannot be well replicated. This is as shown in shown in Figure 4.4, Annex C. |
| NPR001_14088 | The timing of the peak discharge in Lake Samsonvale affects the score for HEH Point 'NPR001_14088'. Given that this is a downstream location within the model, and the modelled hydrograph shapes show a very good match, this is considered a good result for the existing conditions. It is noted that the hydrograph shapes for the future conditions are not as good as the existing conditions but still considered fit for purpose. |

- In general, the stream lag factors are lower at the top of the catchment and become larger downstream. Given the interaction of multiple reaches to the waterbody of North Pine Dam (Lake Samsonvale) a delay was required to achieve the ideal hydrographs at the dam outlet. It would also be expected that the flood wave would travel faster than in normal reaches within this waterbody.
- Storages at road crossings typically required more storage to achieve a match to the TUFLOW result at higher flows, hence the 3rd quartile was used rather than the mean.
- The dummy sub-catchment 'TER010_03DUM' has been included to implement the artificial storage within the 'TER010_02189' HEH area. Four additional dummy sub-catchments have also been included at confluences for the 'design event modelling' points.

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

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**Applied Routing and Artifical Storage**

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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 storms including duration, temporal pattern and the resulting peak discharge for the 1% AEP event at each POI extracted from WBNM HEH and TUFLOW are summarised in Table 5.2.

Table 5.2 Critical storm and peak flows from the UPR WBNM and UPR TUFLOW models at each Design Event Modelling point for the 1% AEP event

| Design Event Modelling Point Name | WBNM Existing Conditions 1% AEP Event | | | | TUFLOW Existing Conditions 1% AEP Event | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Grouping | Duration (minutes) | TP | Peak Discharge ($m^3/s$) | Grouping | Duration (minutes) | TP | Peak Discharge ($m^3/s$) | Difference between WBNM and TUFLOW Peak Discharge (%) |
| KOB032_00957 (*) | ARFa | 270 | 7 | 4.6 | ARFa | 180 | 8 | 4.4 | 4.3% |
| TER010_02189 (*) | ARFa | 120 | 6 | 30.1 | ARFa | 180 | 8 | 29.6 | 1.7% |
| NPR056_01297 (*) (**) | ARFb | 180 | 4 | 13.8 | ARFa | 180 | 8 | 6.6 | 52.2% |
| TER012_00000 | ARFb | 120 | 6 | 48.9 | ARFb | 120 | 6 | 45.4 | 7.2% |
| KOB024_00430 (*) (**) | ARFb | 120 | 8 | 35.9 | ARFb | 120 | 6 | 29.0 | 19.2% |
| TER001_05833 (*) | ARFc | 270 | 2 | 204.3 | ARFd | 360 | 9 | 200.3 | 2.0% |
| KOB018_05953 (*) | ARFc | 270 | 2 | 139.9 | ARFa | 180 | 8 | 136.4 | 2.5% |
| NPR011_DUM01 (*) | ARFc | 270 | 8 | 216.1 | ARFb | 120 | 6 | 206.3 | 4.5% |
| LAC001_11829 (*) | ARFc | 270 | 7 | 172.8 | ARFb | 120 | 6 | 166.5 | 3.6% |
| NPR001_DUM03 (*) | ARFc | 270 | 8 | 210.8 | ARFb | 120 | 6 | 228.1 | 3.4% |
| TER001_04450 (*) | ARFd | 270 | 2 | 313.5 | ARFd | 270 | 7 | 300.7 | 4.1% |
| KOB018_02518 (*) | ARFd | 270 | 2 | 276.8 | ARFa | 180 | 8 | 264.1 | 4.6% |
| TER001_01661 | ARFd | 270 | 7 | 401.9 | ARFd | 270 | 7 | 401.8 | 0.0% |
| NPR001_49127 (*) | ARFd | 270 | 2 | 462.7 | ARFd | 270 | 7 | 497.7 | -7.6% |
| LAC001_11544 (*) | ARFe | 270 | 7 | 464.0 | ARFb | 120 | 6 | 524.6 | -13.1% |
| KOB001_10541 (*) | ARFe | 270 | 7 | 512.3 | ARFb | 120 | 6 | 533.1 | -4.1% |
| KOB001_09533 | ARFe | 270 | 7 | 577.7 | ARFd | 270 | 7 | 584.6 | -1.2% |
| KOB001_DUM01 | ARFe | 270 | 7 | 680.0 | ARFd | 270 | 7 | 678.5 | 0.2% |
| LAC001_05600 (*) | ARFe | 270 | 7 | 733.5 | ARFa | 180 | 8 | 764.9 | -4.3% |
| LAC001_04181 (*) | ARFe | 270 | 7 | 775.8 | ARFa | 180 | 8 | 811.0 | -4.5% |
| NPR001_DUM02 (*) | ARFf | 270 | 7 | 1325.4 | ARFd | 270 | 7 | 1459.9 | 2.6% |
| NPR001_41506 (*) | ARFf | 270 | 7 | 1354.4 | ARFd | 270 | 7 | 1466.0 | -8.2% |
| NPR001_40819 (*) | ARFf | 270 | 7 | 1479.9 | ARFd | 270 | 7 | 1597.0 | -7.9% |
| NPR001_38235 (*) | ARFg | 270 | 2 | 1498.5 | ARFd | 270 | 7 | 1602.3 | -6.9% |
| NPR001_34279 (*) | ARFg | 270 | 8 | 1589.0 | ARFd | 270 | 7 | 1693.4 | -6.6% |
| NPR001_31927 (*) | ARFg | 270 | 8 | 1909.8 | ARFd | 270 | 7 | 1942.9 | -1.7% |
| NPR001_DUM01 (*) | ARFg | 360 | 3 | 2003.5 | ARFd | 360 | 9 | 1996.7 | 8.0% |
| NPR001_13848 (*) | ARFi | 720 | 17 | 1973.8 | ARFd | 360 | 9 | 1816.0 | 4.3% |

**(*) The critical storm identified by analysing WBNM HEH peak flow discharge at the POI was adjusted in liaison with Council after reviewing the TUFLOW model results to ensure more consistent results for broader areas of the floodplain in the TUFLOW flood level grid outputs.**

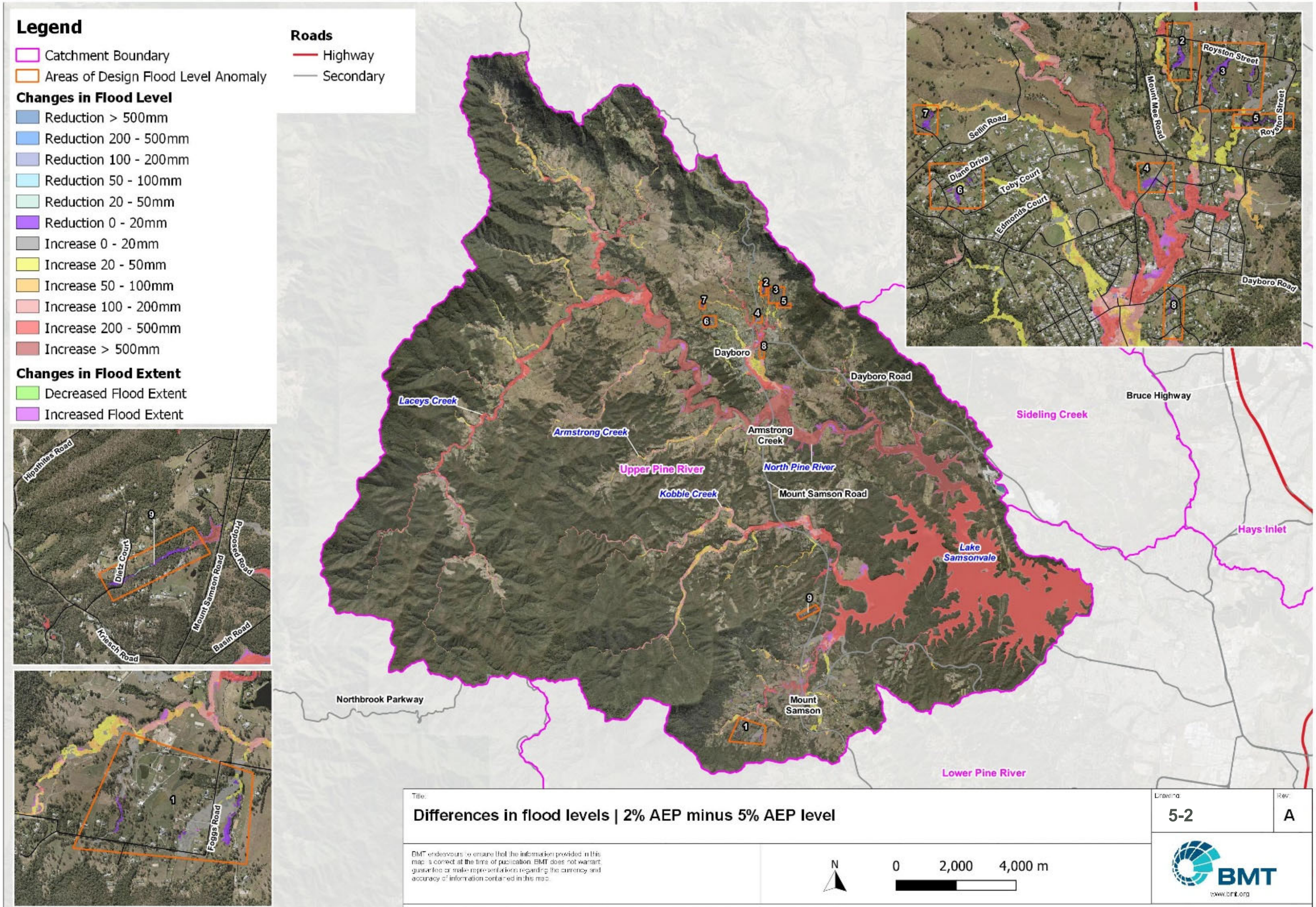
**(**) Anomaly in the TUFLOW model results due to the application of the local inflow hydrograph downstream of the POI and po-line cross section, thus leading to an underestimation of the flow discharge at this POI when compared to the WBNM HEH model results.**

Overall, the comparison between the peak flow discharges estimated with WBNM HEH and TUFLOW models for the same storms highlighted a very good match between the model results at the selected points of interest. However, the initial selection of critical storms based on WBNM HEH peak discharge results at the POI was adjusted after review of the TUFLOW model results in liaison with Council in order to obtain more consistent results throughout broader areas of the floodplain and minimise flood level inconsistencies between AEP events in the TUFLOW outputs. It is noticed that these areas of anomalies are mainly located at the very top of a tributary where shorter durations would be critical.

Two locations were identified as anomalies at POI NPR056_01297 and KOB024_00430, where the TUFLOW peak discharges are approximately 52% and 19% lower than the WBNM HEH peak discharge. At these locations, the sa local inflow polygons included in the TUFLOW model are located downstream of the POI po-line, thus leading to an underestimation of the peak discharge in TUFLOW when compared to WBNM HEH. The issues at those 2 locations can be amended in future model upgrades by adding po-lines downstream of sa local inflow polygons in TUFLOW and compare the TUFLOW and WBNM HEH results for these POIs at the new po-lines.

The final design event grids generated by TUFLOW exhibited overall consistent results across AEP events and scenarios, with the only exception of few small areas affected by level inconsistencies as summarised in the following points:

- The 5% AEP flood level grid is higher than the 2% AEP flood level grid at the eight locations shown in Figure 5.2. These differences in flood level range between 0mm and 20mm, however, most differences are smaller than 10mm. The areas affected by inconsistencies range between 0.5ha and 2ha, i.e. these areas are very small.
- The 1% AEP flood level grid is higher than the 0.1% AEP flood level grid by approx. 90mm at the small dam shown in Figure 5.3. These inconsistencies are due to a change in flowpath between the 1% and 0.1% AEP events at this location.

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**Differences in flood levels | 2% AEP minus 5% AEP level**

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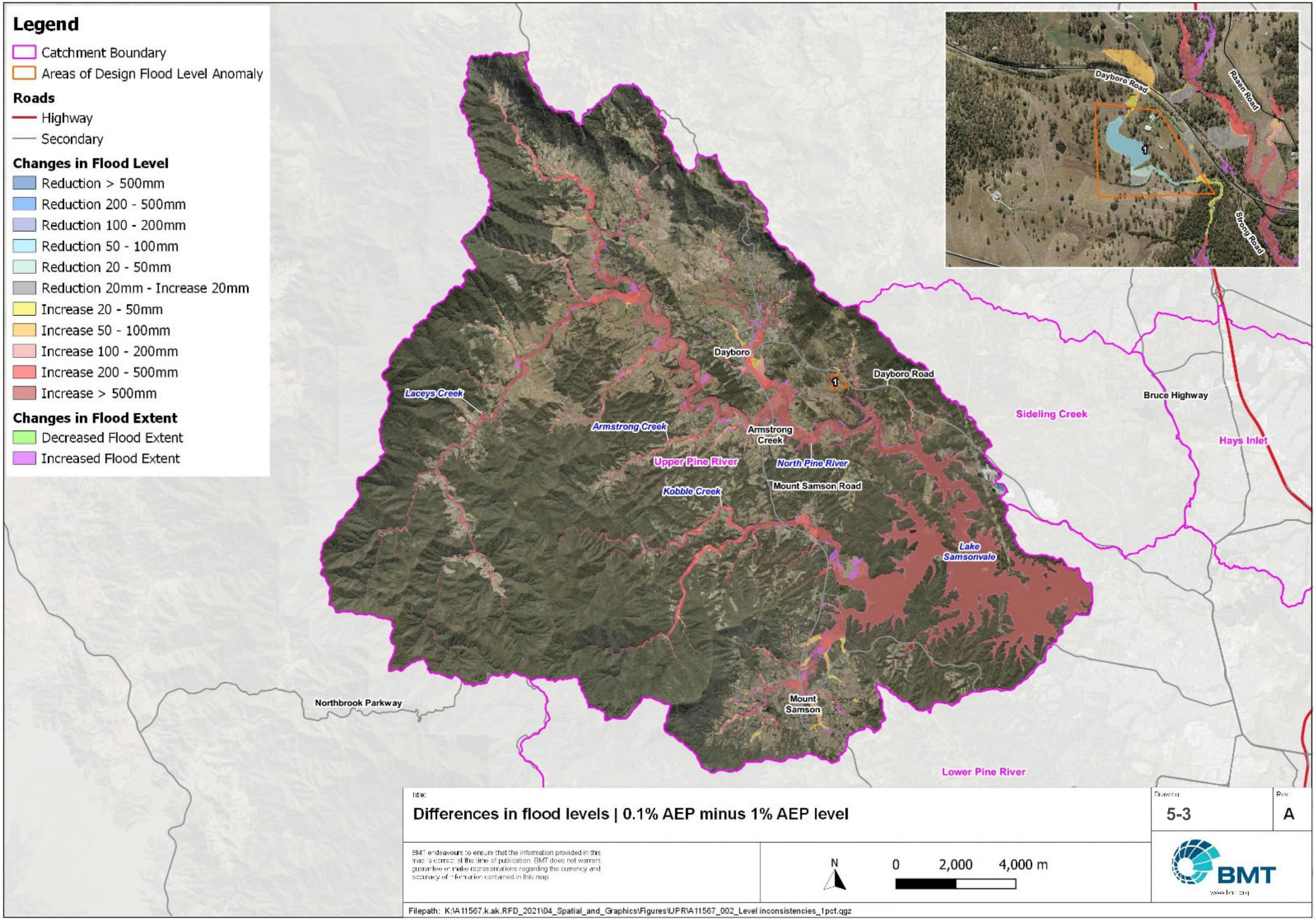


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**Differences in flood levels | 0.1% AEP minus 1% AEP level**

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### 2022 vs 2014 Existing Conditions

Differences in flood levels and extent were observed when comparing the 2022 and 2014 RFD flood level grids in the 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, the updated downstream boundary (North Pine Dam rating curve) 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 comparison between the 2014 RFD 1% AEP flood level grid and the 2022 RFD 1% AEP existing unblocked scenario flood level grid is shown in Figure 5.4. The key changes in flood levels can be summarised as follows:

- An overall decrease in flood levels was observed at North Pine Dam (also called Lake Samsonvale). These decrease ranges between 100mm and 2.7m in the 5% AEP event, between 400mm and 2.15m in the 1% AEP event, and between 400mm and 2.1m in the 0.1% AEP event. Please note that in the RFD 2014 simulations North Pine Dam was represented using 1d elements and, hence, was not included in the 2d final grids. As a consequence, Figure 5.4 shows a “increased flood extent” in North Pine Dam which is artificially related to the model schematisation. The RFD 2022 simulations are characterised by lower flood levels throughout the dam due to the change in rating curve applied to the RFD 2022 simulations when compared to the RFD 2014 simulations.
- An increase in flood levels was observed in proximity of the Armstrong Creek township in all the analysed events. The increase ranges between 250mm and 1.5m in the 5% AEP event, between 250mm and 2.1m in the 1% AEP event, and between 250mm and 2.6m in the 0.1% AEP event. These increases mainly affect rural areas.
- An increase in flood levels was observed at Dayboro in all the analysed events. The increase ranges between 20mm and 575mm in the 5% AEP event, between 20mm and 270mm in the 1% AEP event, and between 20mm and 200mm in the 0.1% AEP event.
- An increase in flood levels was observed along Laceys Creek in all the analysed events. The increase ranged between 50mm and 2.3m in the 5% AEP event, between 100mm and 1.5m in the 1% AEP event, and between 100mm and 1.3m in the 0.1% AEP event. These increases mainly affect rural areas.
- An overall increase in flood levels ranging between 100mm and 950mm was also observed along Kobble Creek in the 5% AEP event. These increases mainly affected rural areas.
- An increase in flood levels ranging between 50mm and 690mm is also observed in proximity of Mount Samson township in the 5% AEP event. These increases mainly affect rural areas.

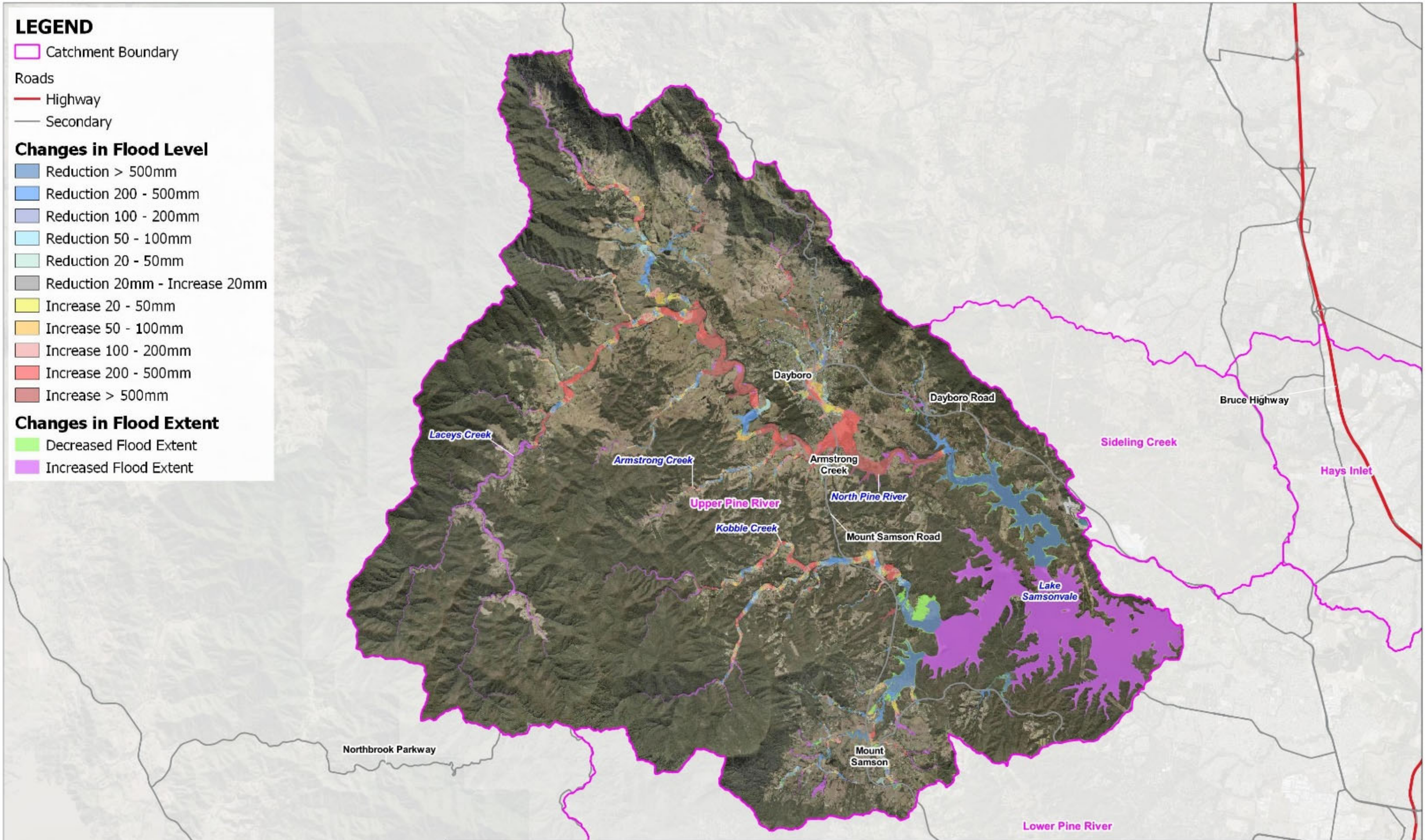
The application of blockage factors to the culverts in the blocked scenarios produced higher flood levels upstream of the culverts and lower flood levels downstream of the culverts when compared to the unblocked scenarios.

### 2022 vs 2014 Future Conditions

The comparison between the 1% AEP future envelope of blocked and unblocked scenarios and the 2014 DFE MDS grid is shown in Figure 5.5.

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:

- A reduction in flood levels ranging between 60mm and 200mm was observed in the northern branch of Lake Samsonvale. An increase in flood levels ranging between 85mm and 100mm was observed in the western branches of Lake Samsonvale.
- An increase in flood levels ranging between 270mm and 2.5m was observed in proximity of the Armstrong Creek township. These increases mainly affect rural areas.
- An increase in flood levels up to 370mm was observed at Dayboro.
- An increase in flood levels up to 1m were also observed along Laceys Creek. These increases mainly affect rural areas.
- An increase in flood levels ranging between 130mm and 575mm was also observed in proximity of Mount Samson township.

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**1% AEP comparision 2022 vs 2014 (unblocked)**

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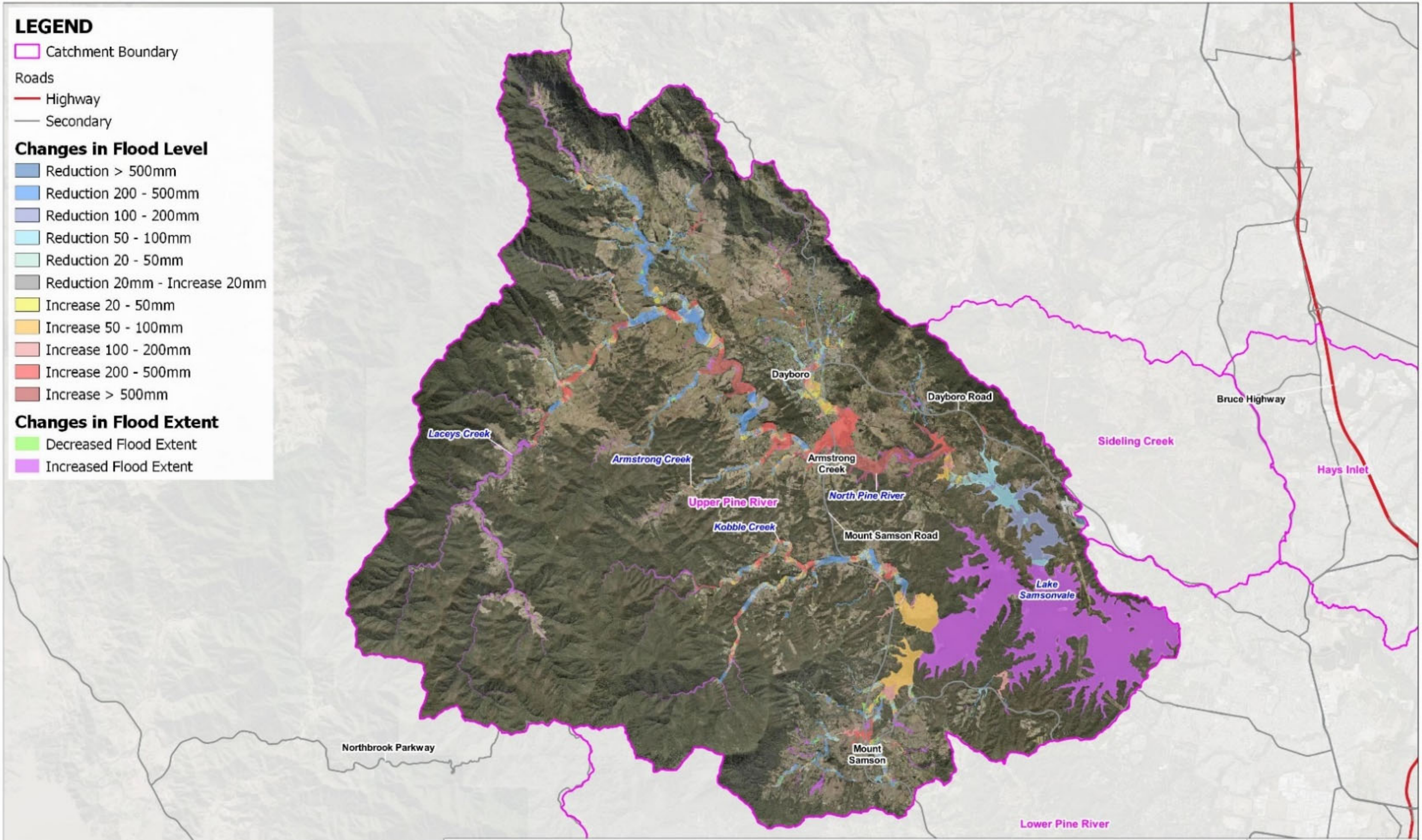


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**Comparison 2022 future 1% AEP vs 2014 DFE**

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## 5.4 Model Limitations and Quality

Watercourses within the Upper Pine River 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 either 2, 3 or 4 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 shows the UPR 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 UPR TUFLOW simulations were performed 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 18-hour | 9.6 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 10% AEP 18-hour | 10.3 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 5% AEP 6-hour | 3.9 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 2% AEP 6-hour | 3.9 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 1% AEP 6-hour | 5.3 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 0.1% AEP 6-hour | 5.3 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |
| 0.05% AEP 6-hour | 5.3 hours | 5.8 GB | NVIDIA GeForce RTX 2080 Ti |

# 6 Conclusion

The Upper Pine River (UPR) WBNM and TUFLOW models were updated, and model calibration and verification were undertaken to the 2022, 2011 and 2017 historic events.

Overall calibration and validation of the UPR catchment to historical events is considered satisfactory. A very good match of the recorded and modelled hydrographs was achieved at the gauges in all events.

An HEH model was developed for the Upper Pine River 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 takes into account 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 of HEH points within the Upper Pine River catchment. For most of the HEH points (72%) an "excellent: score was achieved. For the remaining HEH points, there was an equal split, some HEH points (7%) achieved a 'good' score and other HEH points (7%) are not within the desired range. Overall, this is considered a very good result. 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 are 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 Annex C for more details). For each design event 2, 3 or 4 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 UPR models are considered fit for purpose for use in floodplain planning and flood forecasting.

Although the model is considered fit for purpose, some improvements can be performed in future model updates in accordance with the following recommendations:

- 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 require 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 can lead to 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 in order 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 wasting 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 (e.g., resolution ~0.1m) in the creeks to improve the simulation of low flows in preparation for riverine water quality modelling.
    - Install water quality gauges in the catchments to inform future riverine water quality modelling.

# Annex A Model Calibration: UPR 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) |
| Doc Ref: | T.A11567.015_Model_Calibration_UPR | | |
| Subject: | Model Calibration: UPR Catchment | | |

# 1 Introduction

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

The UPR catchment has been calibrated to the events of January 2011 and February 2022. It was then validated to the event of March 2017 using the SID WBNM model and TUFLOW HPC model without the sub grid sampling (SGS) feature and a grid resolution of 5m.

Of these three events, the 2011 and 2022 were the most significant across the UPR catchment and the 2017 event was notably smaller.

Table 1.1 summarises the events modelled.

Table 1.1 Modelled Events: UPR

| Event | Model Start | Model End | Simulation Period (h) | Accumulated Rainfall during the event at Dayboro WWTP AL |
|---|---|---|---|---|
| January 2011 | 09/1//2011 00:00 | 12/1/2011 18:00 | 90 | 550mm |
| March 2017 | 29/3/2017 12:00 | 2/4/2017 16:00 | 100 | 280mm |
| February 2022 | 23/02/2022 06:00 | 28/2/2022 06:00 | 120 | 900mm |

# 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 2.3.

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 - UPR

| Gauge Name | Gauge ID | 2011 | 2017 | 2022 |
|---|---|---|---|---|
| Baxters Creek AL | 540189 | ✓ | ✓ | ✓ |
| Browns Creek Road AL | 540411 | ✓ | ✓ | ✓ |
| Cedar Creek Rd AL | 540444 | ✓ | ✓ | ✓ |
| Clear Mountain AL | 540418 | ✓ | ✓ | ✓ |
| Dayboro (Mt Mee Rd) AL | 540628 | | ✓ | ✓ |
| Dayboro AL | 540410 | | ✓ | |
| Dayboro WWTP AL | 540484 | ✓ | ✓ | ✓ |
| Kluvers Lookout AL | 540168 | ✓ | ✓ | ✓ |
| Kobble Creek (Ladies Rd) | 540656 | | ✓ | ✓ |
| Laceys Creek AL | 540409 | ✓ | ✓ | ✓ |
| Moorina AL | 540358 | ✓ | ✓ | ✓ |
| Lake Kurwongbah AL | 540204 | | | ✓ |
| Mt Glorious AL P | 540138 | | ✓ | |
| Mt Mee AL P | 540185 | ✓ | | |
| Mt Samson Rd AL | 540447 | ✓ | | ✓ |
| North Pine Dam AL | 540202 | ✓ | ✓ | |
| Ocean View AL | 540634 | | ✓ | ✓ |
| Raynbird Creek AL | 540545 | | ✓ | ✓ |

## 2.2 Stream Gauges

Stream gauges that recorded event water levels are listed in Table 2.2. Data for these gauges was provided by Council. Stream gauges are used in the calibration by plotting the recorded level against the modelled levels and assessing the match to flood peak, timing, volume and hydrograph shape.

Table 2.2 Available Stream Gauges

| Gauge Name | Gauge ID | Watercourse | 2011 | 2017 | 2022 |
|---|---|---|---|---|---|
| Kobble Creek Alert | 540656 | Mt Samson Creek | ✓ | | ✓ |
| Baxters Creek Alert | 540189 | North Pine River | ✓ | ✓ | ✓ |
| Dayboro (Mt Mee Road) Alert | 540628 | Terrors Creek | | ✓ | ✓ |
| Dayboro WWTP Alert | 540484 | North Pine River | Gauge Failed | ✓ | ✓ |
| North Pine Dam Alert | 540202 | Lake Samsonvale | ✓ | ✓ | ✓ |

## 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 e.g. 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.

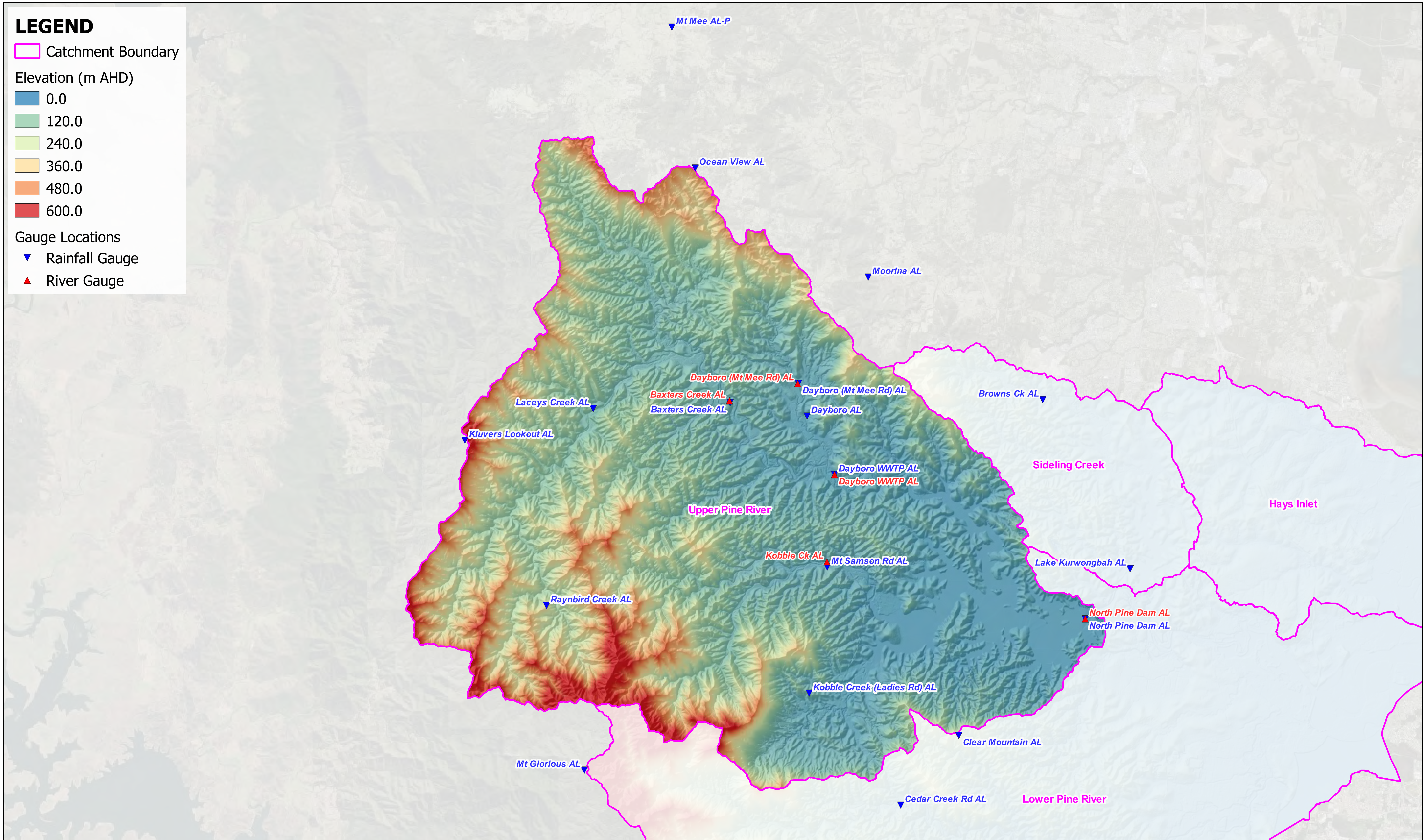
Notwithstanding the above uncertainties, flood marks, when collected in sufficient quantities, can provide a valuable overview of peak flood levels as greater confidence can be placed in the surveyed elevations when they corroborate with each other. For example, a cluster of flood marks in close spatial 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.

Table 2.3 lists the number of available flood marks in the UPR catchment by event.

Table 2.3 Flood Marks

| Event | Number of flood marks | Number of flood marks used |
|---|---|---|
| 2011 | 35 | 35 |
| 2017 | 16 | 16 |
| 2022 | 52 | 52 |




Title:

**Rainfall and stream gauges used for UPR calibration**

Figure: **Fig 2.1**

Rev: **A**

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# 3 January 2011 Calibration Event

## 3.1 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.

The rainfall resulted in largest recorded release from North Pine Dam (2,854m$^3$/s at the peak) and led to extensive flooding on the Lower North Pine River.

Total rainfall depths ranging between 200mm and 580mm were experienced across the UPR catchment.

Figure 3.1 shows the cumulative plot of rainfall at available gauges. Figure 3.2 shows the distribution of rainfall applied in the WBNM model.

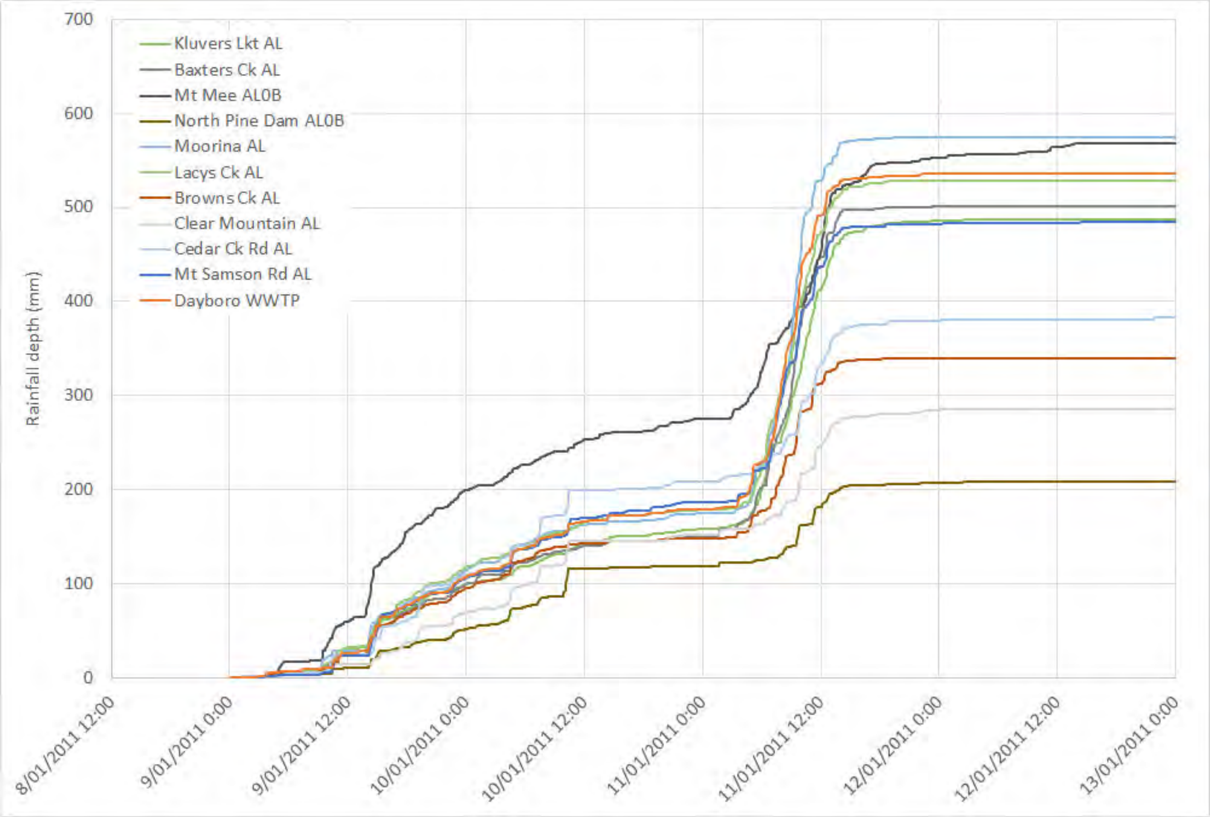
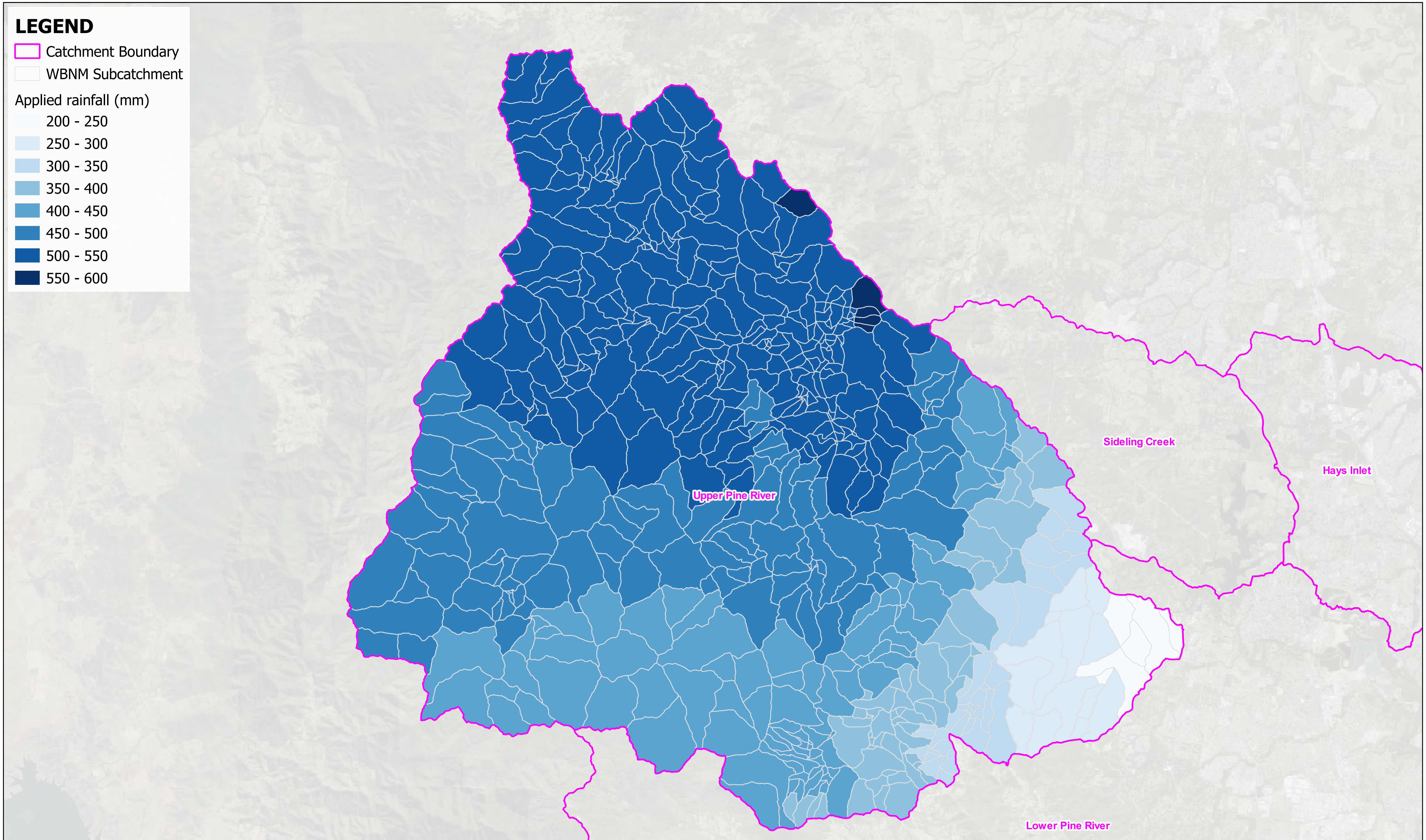



Figure 3.1 January 2011 Event: Cumulative Rainfall Plot




Title:
**January 2011 Event Rainfall applied in model**

Figure: Fig 3.2

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## 3.2 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 calibration. The calibration is presented as follows:

- Figure 3.3 plots the calibration at stream gauges with available recorded data.
- Figure 3.4 shows the difference in peak level (modelled result minus recorded value) at flood marks
- Figure 3.5 presents a histogram of differences between modelled and recorded values at flood marks.

Key summary points noted from the results are provided below:

- A good match to the peak level was achieved at Kobble Creek Alert. The modelled hydrograph appears to underestimate the lower falling limb in this and other calibration events. A baseflow (ground water recharge) component may have influenced the lower receding limb of the recorded flow hydrograph.
- A very good match in hydrograph, peak, shape and timing is achieved at the Baxters Creek Alert gauge. It is noted that the 2011 event is the largest of the three modelled events at this gauge.
- The Dayboro WWTP Alert gauge failed during the 2011 flood event whilst a very good match at the peak water level was achieved at North Pine Dam Alert gauge.
- The flood marks indicate that the calibration is reasonable although tends to result in lower modelled flood levels than recorded levels in some cases, particularly in the vicinity of Williams Street near Terrors Creek.

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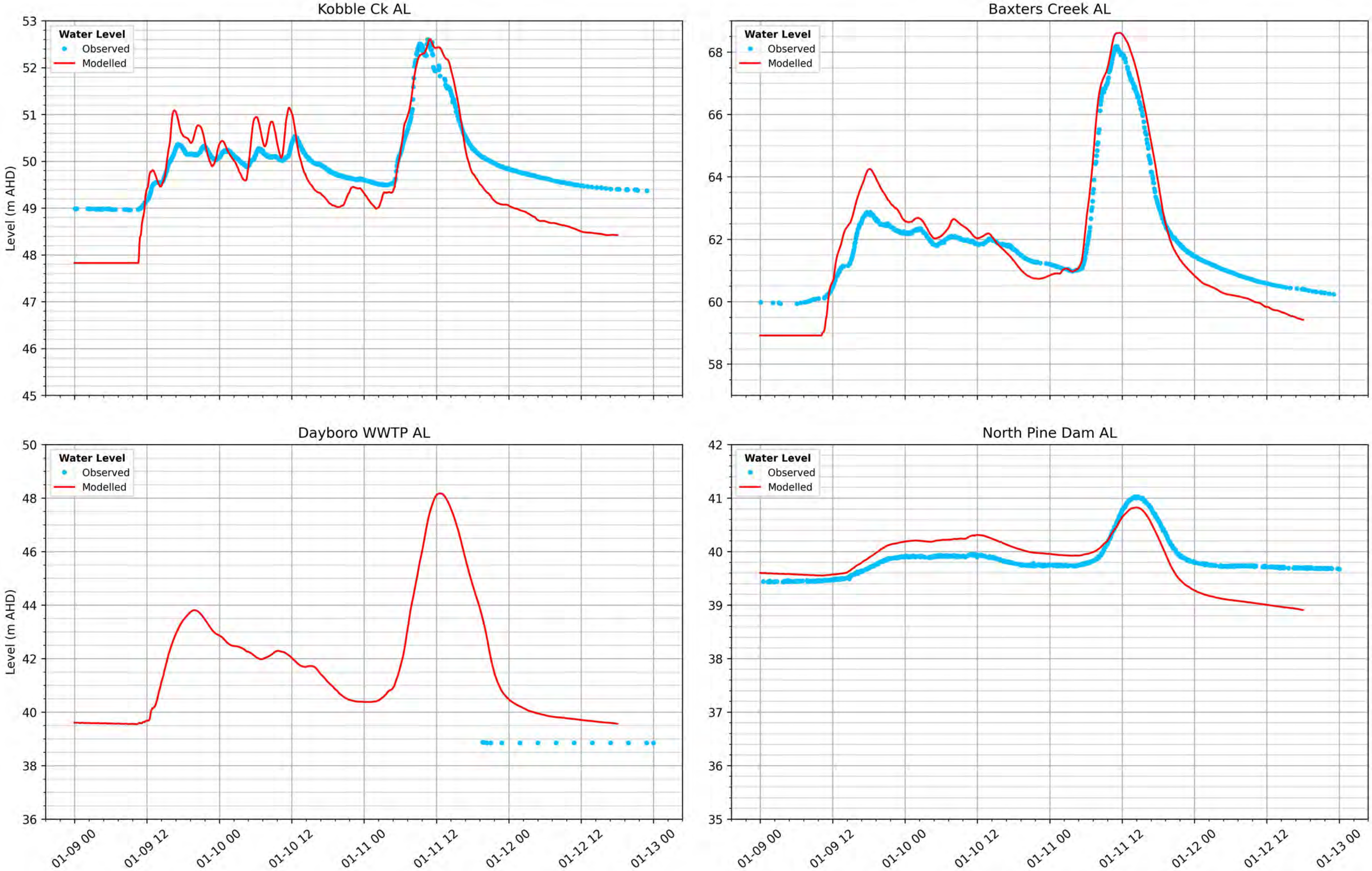
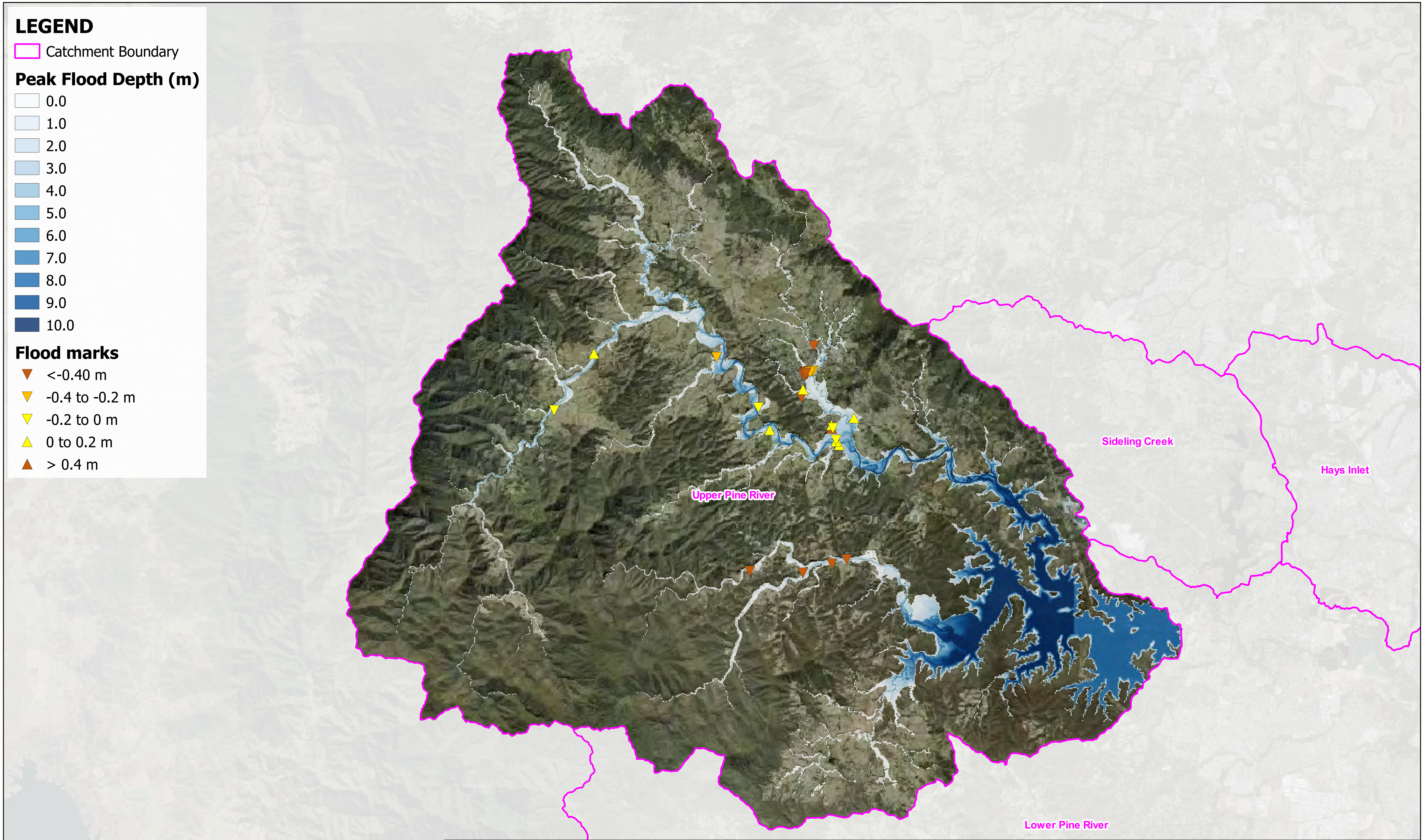
# 2011 Upper Pine River Water Level at Gauges






Title:

**January 2011 Event: Calibration to Flood Marks**

Figure: **Fig 3.4**

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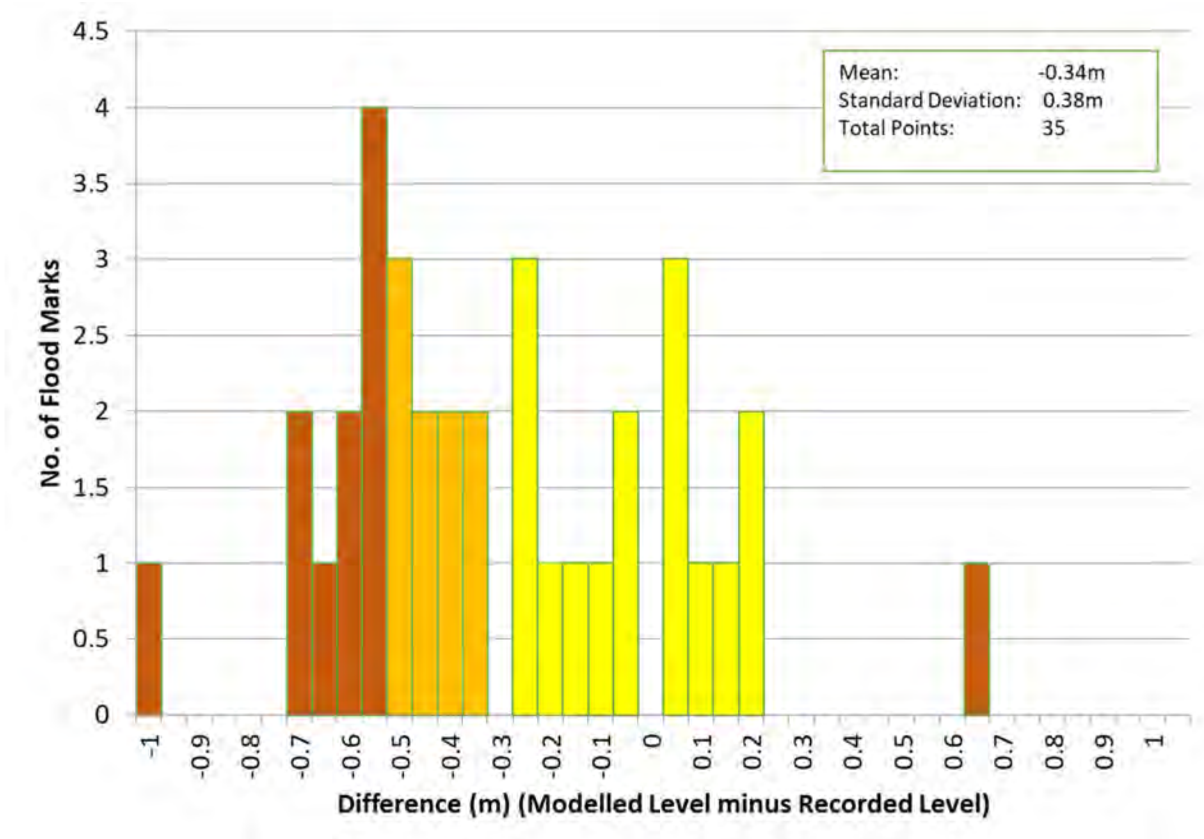



Figure 3.5 January 2011 Event: Histogram of Differences in Level to Flood Marks

# 4 February Calibration 2022 Event

## 4.1 Event Rainfall

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). Variations in rainfall intensity throughout the event led to multiple runoff peaks. Event rainfall totals ranging between 650mm and 1000mm were recorded at gauges throughout the catchment and surrounding area. Figure 4.1 plots the cumulative event rainfall at gauges used in the assessment.

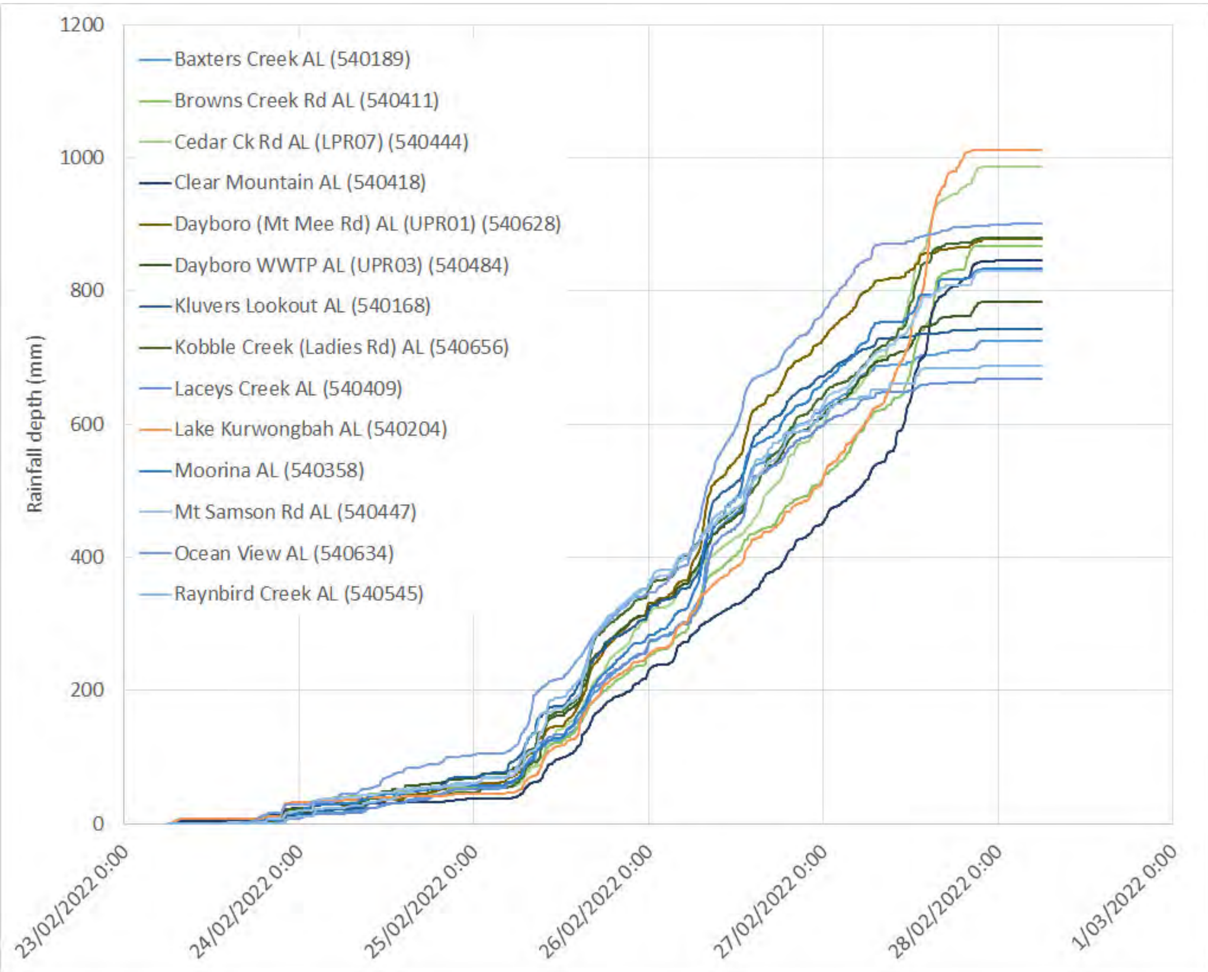
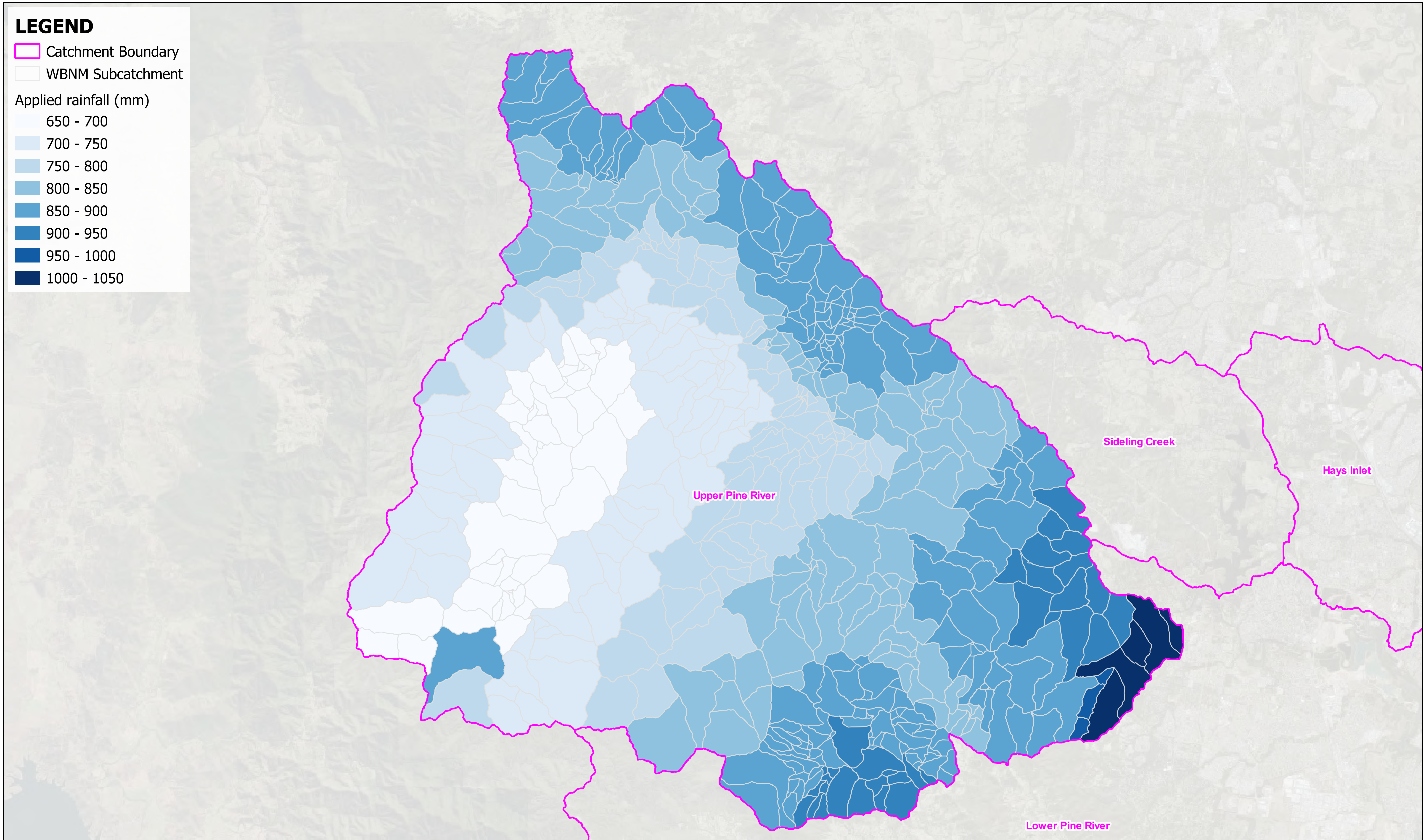



Figure 4.1 February 2022 Event: Cumulative Rainfall Plot




Title:
**February 2022 Event Rainfall applied in model**

Figure: Fig 4.2

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## 4.2 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. The calibration is presented as follows:

- Figure 4.3 plots the calibration at stream gauges with available recorded data.
- Figure 4.4 shows the difference in peak level (modelled result minus recorded value) at flood marks
- Figure 4.5 presents a histogram of differences between modelled and recorded values at flood marks.

Key summary points noted from the results are provided below:

- At Baxters Creek Alert, the overall shape of the hydrograph is replicated well in the model with the model capturing the multiple peaks which occurred throughout the event.
- At Dayboro (Mt Mee Road) Alert gauge the rising limb is characterised by a series of minor peaks, with progressively increasing water levels until the highest peak. This would have been in response to multiple rainfall bursts. The model exhibits similar response and replicates the general shape of the hydrograph although the peaks are underestimated in the model, including the largest peak on 26 February. This is likely due to the nature of rainfall, which is not able to be represented using a limited number of rain gauges.
- A good match to the recorded data is shown at Kobble Creek Alert and Dayboro WWTP gauges with the peak, timing and shape of the hydrographs matching well.
- A good match is achieved at the North Pine Dam Alert gauge. Similar to other gauges, the model replicates the shape of the hydrograph throughout the event.
- At the majority of the 52 flood marks, the model shows a good agreement to the recorded values with a slight overall trend for overprediction.

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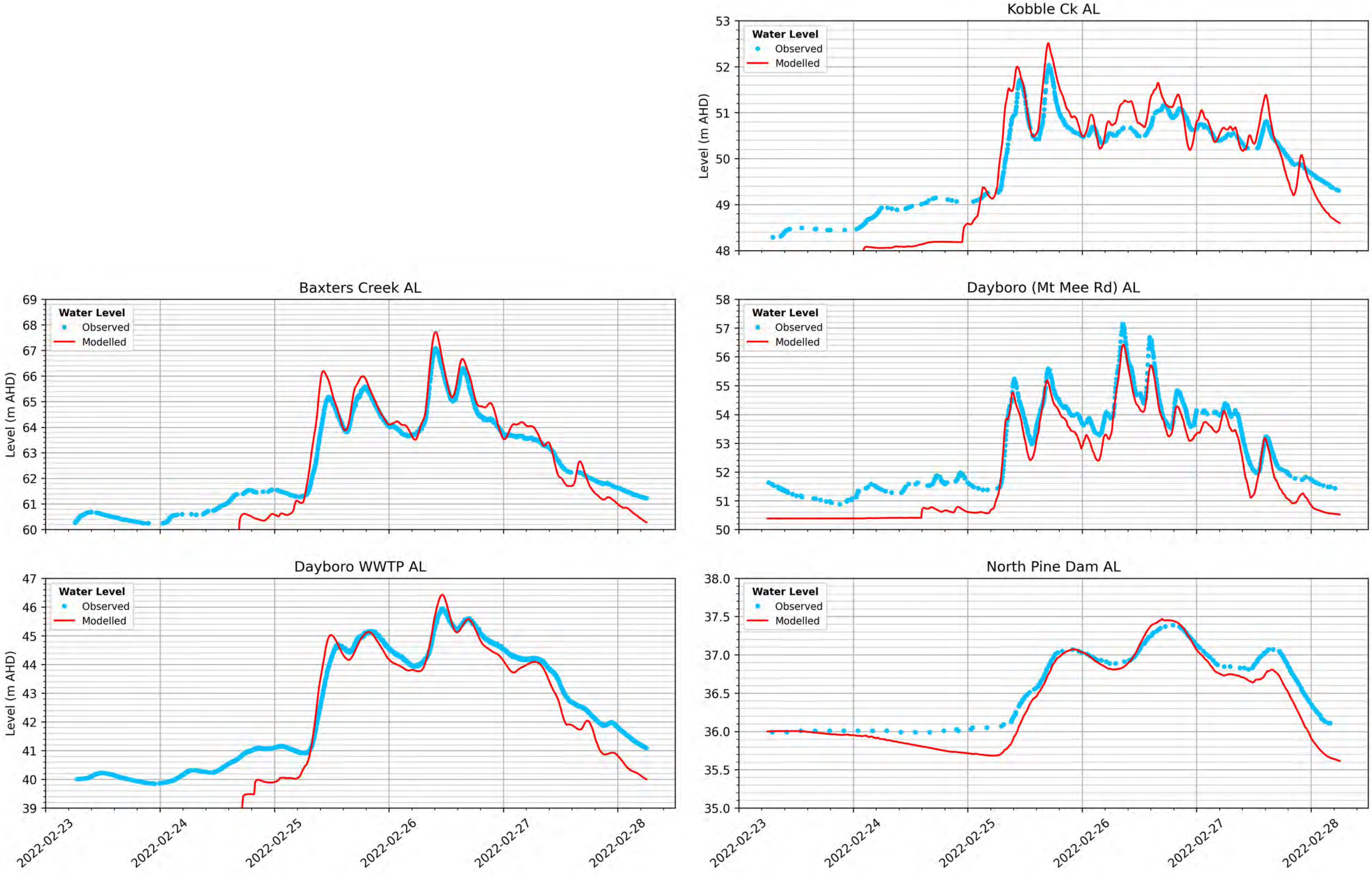
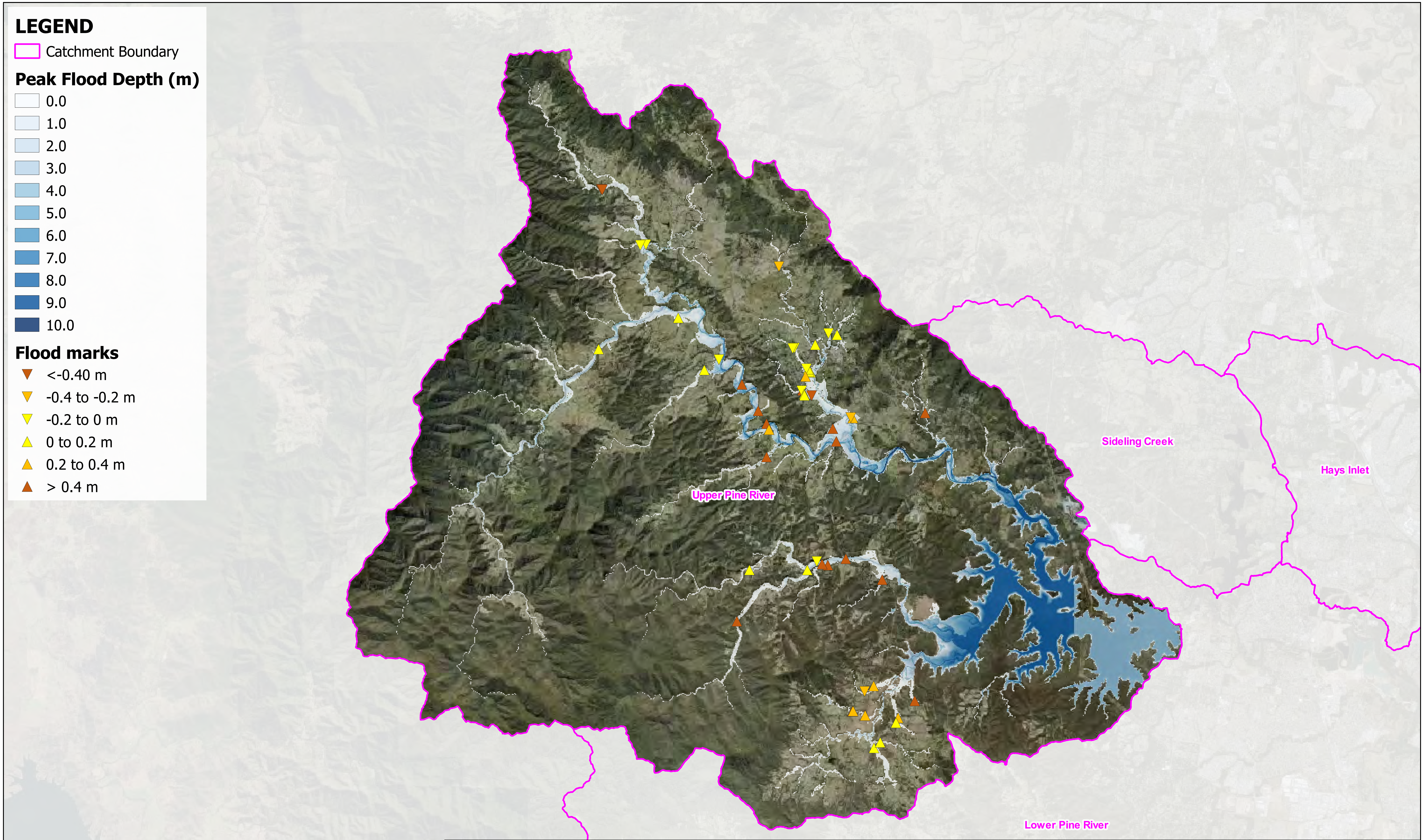
# 2022 Upper Pine River Water Level at Gauges






Title:

**February 2022 Event: Calibration to Flood Marks**

Figure: Fig 4.4

Rev: A



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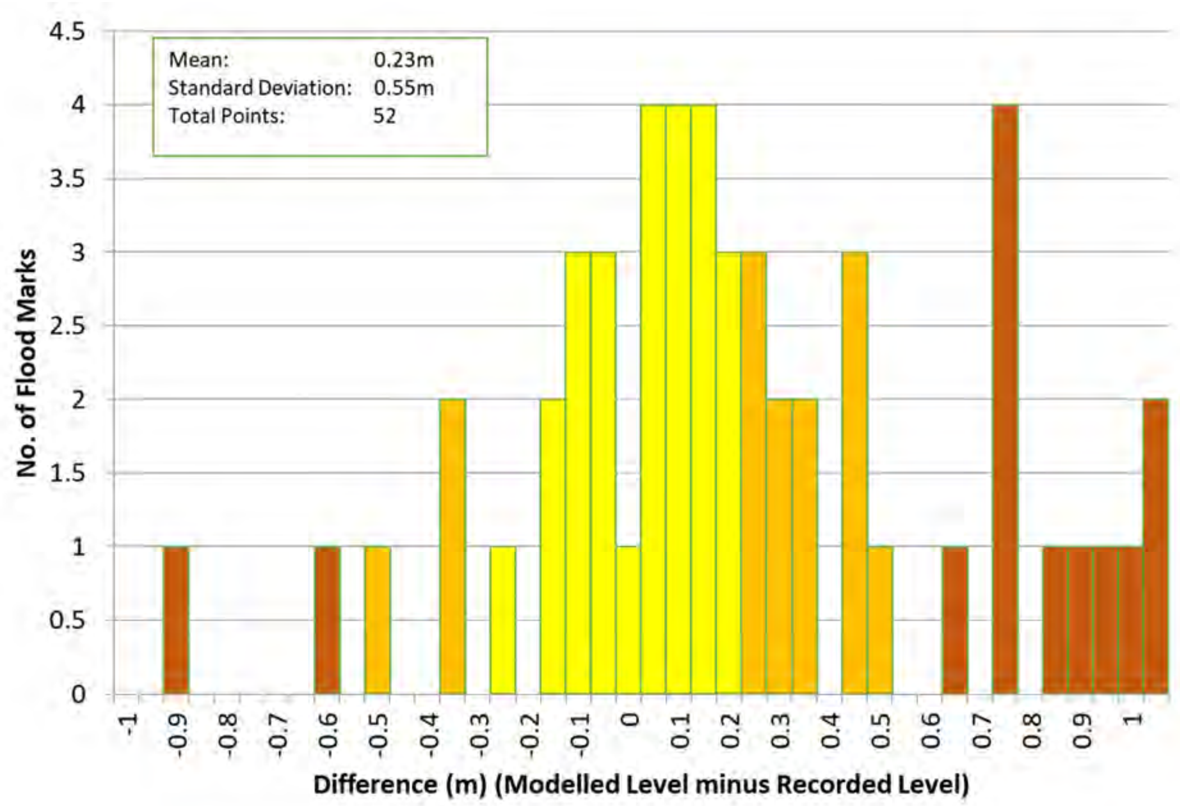



Figure 4.5 February 2022 Event: Histogram of Differences in Level to Flood Marks

# 5 March 2017 Validation Event

## 5.1 Event Rainfall

The March 2017 event is the smallest of the three flood events modelled for the UPR catchment and occurred during the 30 March 2017 with the rainfall falling within a 24-hour period. A relatively large variation in event rainfall depths were recorded within the catchment and surrounding area ranging between 120mm and 370mm across a 24-hour period. Figure 5.1 shows the cumulative event rainfall at gauges used in the assessment.

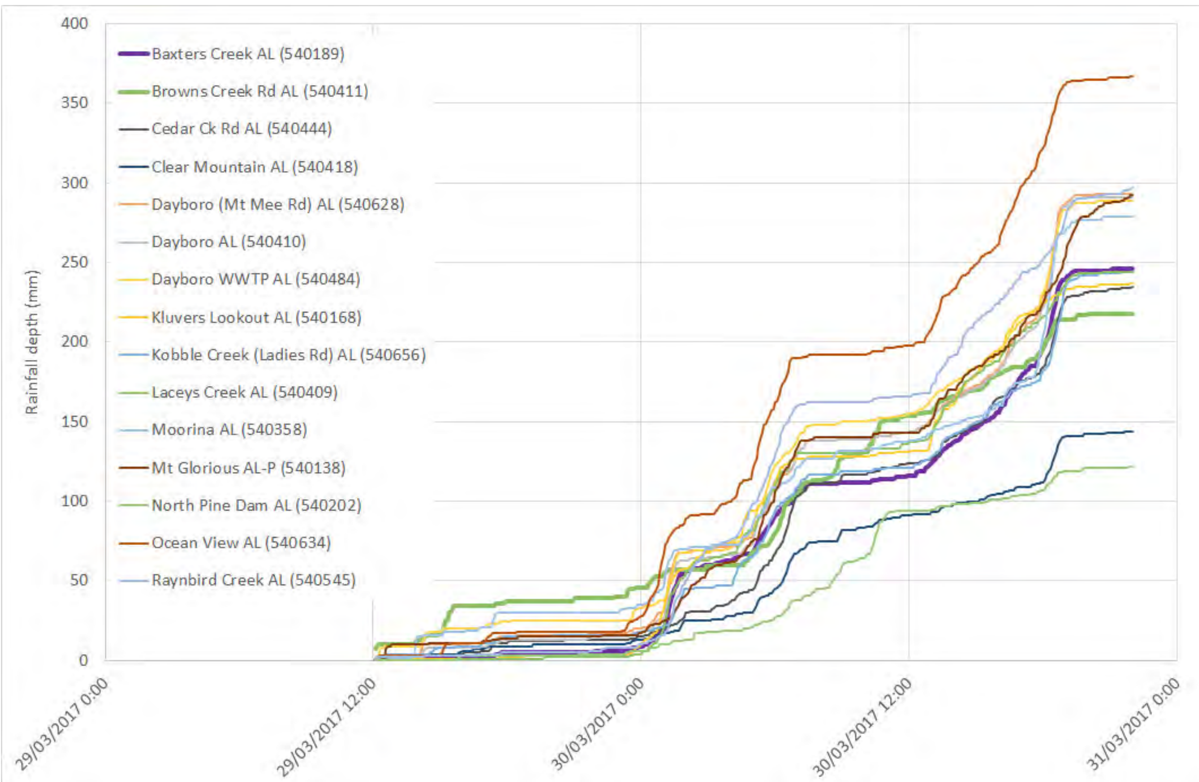
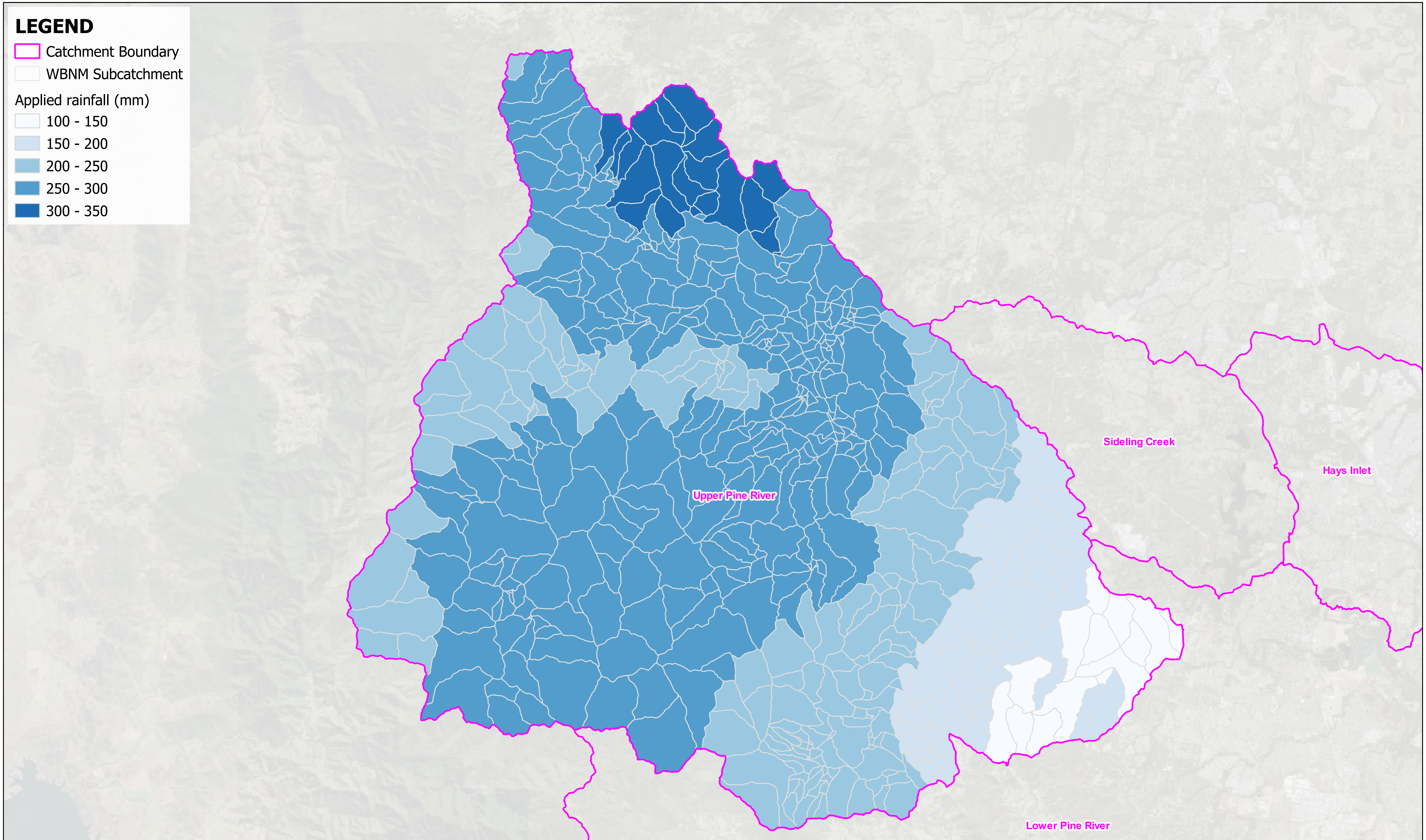



Figure 5.1 March 2017 Event: Cumulative Rainfall Plot




Title:
**March 2017 Event Rainfall applied in model**

Figure: **Fig 5.2**

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## 5.2 Validation Results and Discussion

Rainfall loss values of 70 mm initial loss and 5.0 mm/h continuing loss were adopted for the 2017 event calibration. The validation is presented as follows:

- Figure 5.3 plots the calibration at stream gauges with available recorded data.
- Figure 5.4 shows the difference in peak level (modelled result minus recorded value) at flood marks
- Figure 5.5 presents a histogram of differences between modelled and recorded values at flood marks.

Key summary points noted from the results are provided below:

- The rising limb of the Dayboro (Mt Mee Road) Alert gauge is characterised by two initial peaks in water level followed by a main peak. The first two smaller peaks on the rising limb are not well matched, whilst the peak level, shape and timing of the main peak is well matched.
- The modelled hydrograph although slightly overstated, is providing a reasonable fit in terms of water levels and timing at Baxters Creek Alert and Dayboro WWTP Alert gauges.
- The Kobble Creek Alert gauge failed during the 2017 flood event.
- A very good match is achieved at North Pine Dam Alert gauge. It is understood that no releases were made from the dam during this event and so the highest water level is at the end of the event.
- At the majority of the 16 flood marks, the model shows a good agreement to the recorded values with a slight overall trend for overprediction.
- A high continuing loss of 5mm/hr was found to provide the best overall fit for the 2017 validation event. It is likely that modelled rainfall in this event is overstated and hence the need for a high continuing rainfall loss.

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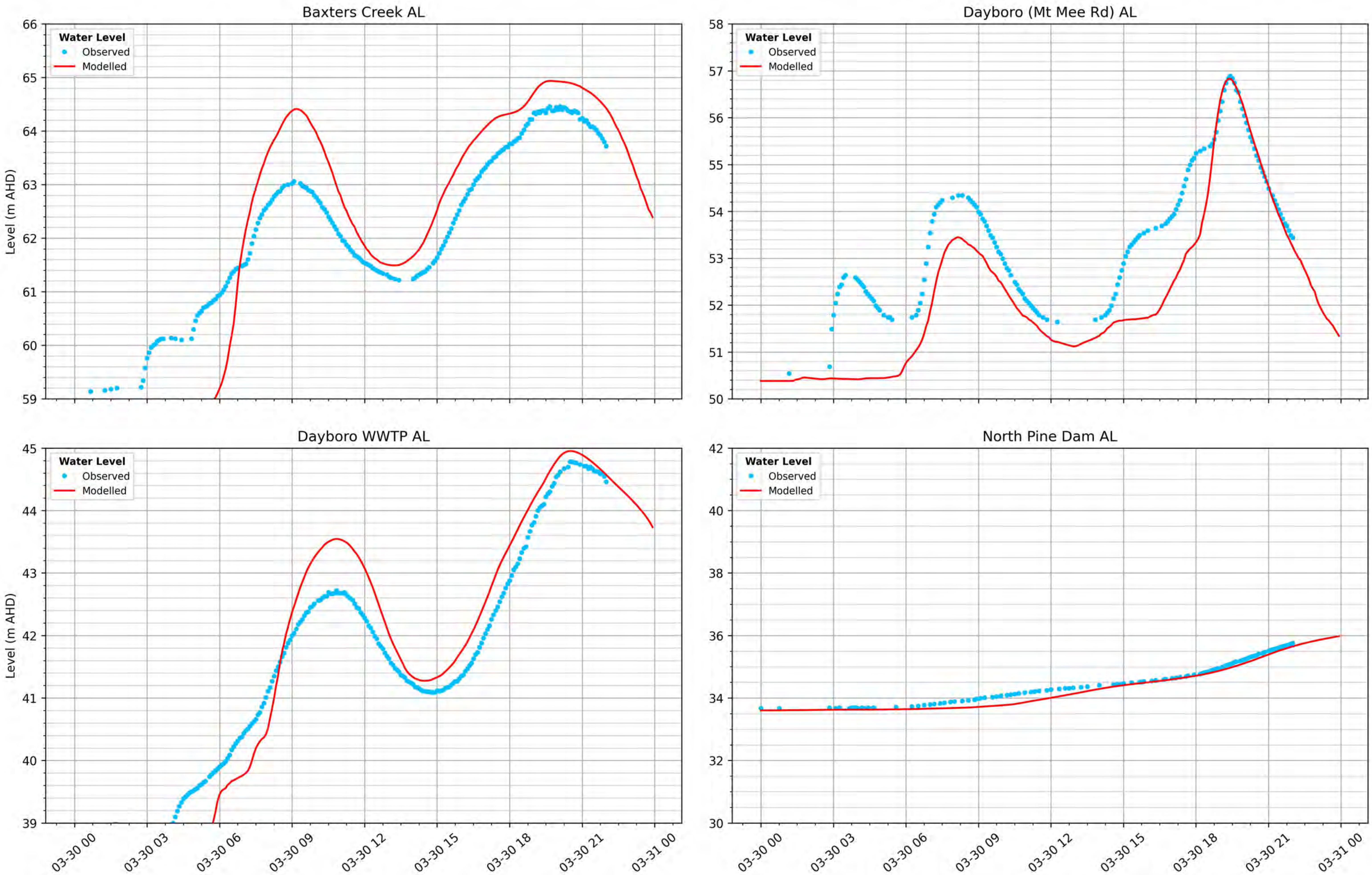
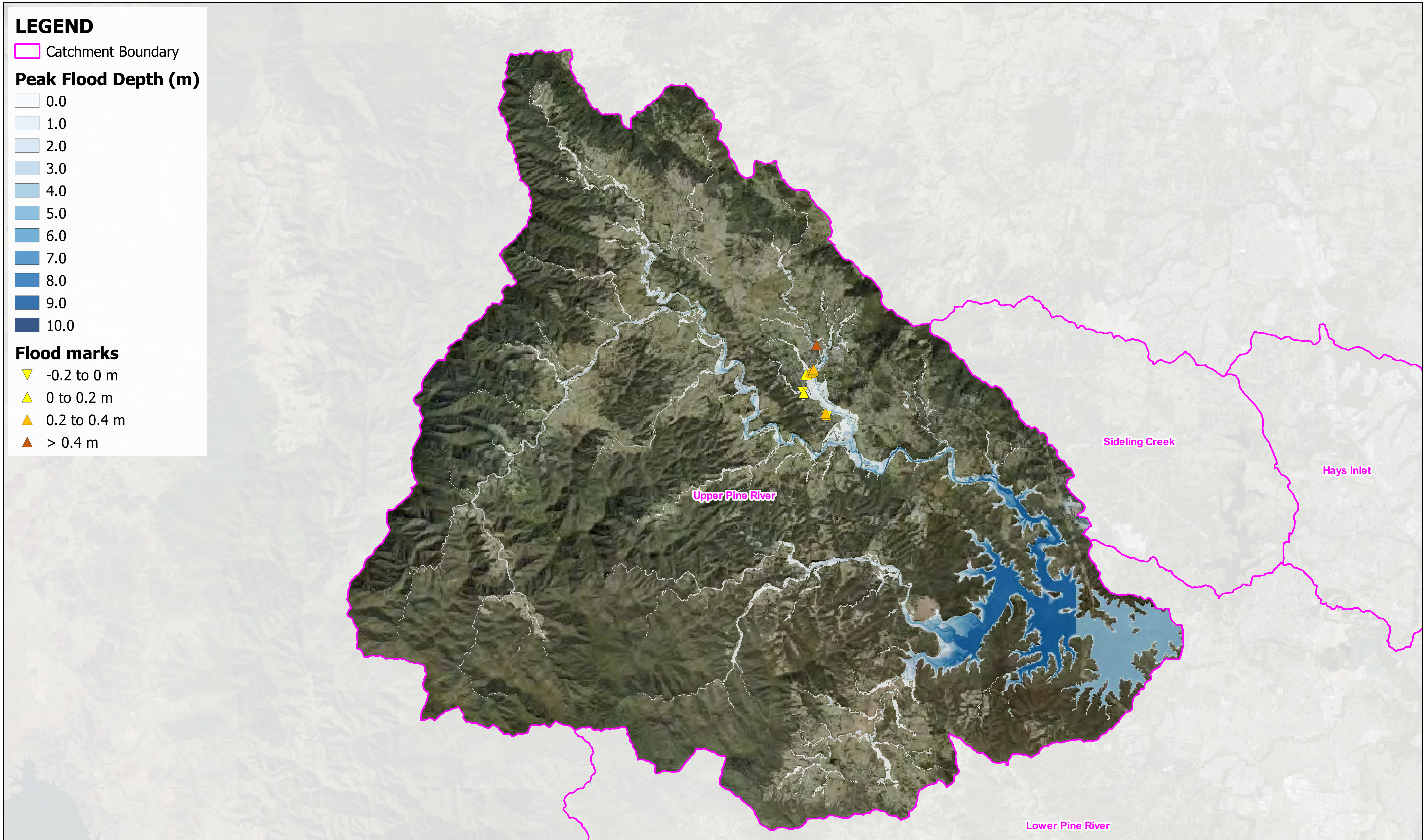
# 2017 Upper Pine River Water Level at Gauges






Title:
**March 2017 Event: Calibration to Flood Marks**

Figure: **Fig 5.4**

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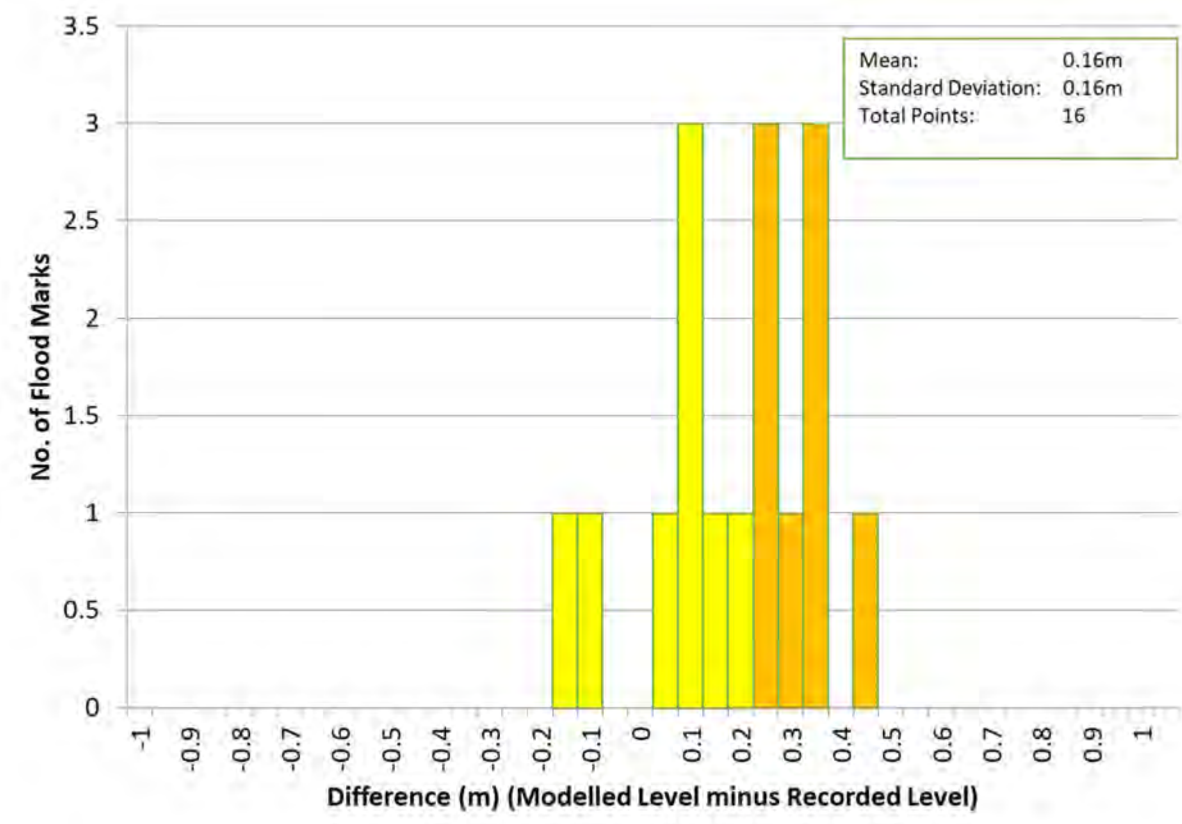


Figure 5.5 March 2017 Event: Histogram of Differences in Level to Flood Marks

# 6 Conclusions

Overall calibration and validation of the UPR catchment to historical events is considered satisfactory. A very good match in hydrograph, peak, shape, and timing is achieved at most gauges in all events. The calibration for all events was achieved using a consistent set of Manning's n roughness values. It is recommended that this same set of values is used for design flood modelling.

A continuing loss of 1mm/hr was adopted for both calibration events (2022 and 2011), whilst the initial losses showed a large variation, but this is to be expected given that the initial loss is heavily dependent on antecedent catchment conditions, which can be highly variable between events. A high continuing loss of 5mm/hr was adopted for the 2017 calibration event to account for the realistic volume of rainfall in the catchment. A better representation of rainfall distribution in the catchment may allow for a similar continuing loss estimate to the calibration events.

Overall, the model shows good agreement to the recorded flood marks for all events with a slight underprediction in the 2011 event, and a slight overprediction in the 2017 and 2022.

# Annex B HEH Modelling Methodology

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# Technical Note

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

## Overview

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

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

## Aim

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

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

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

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

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

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

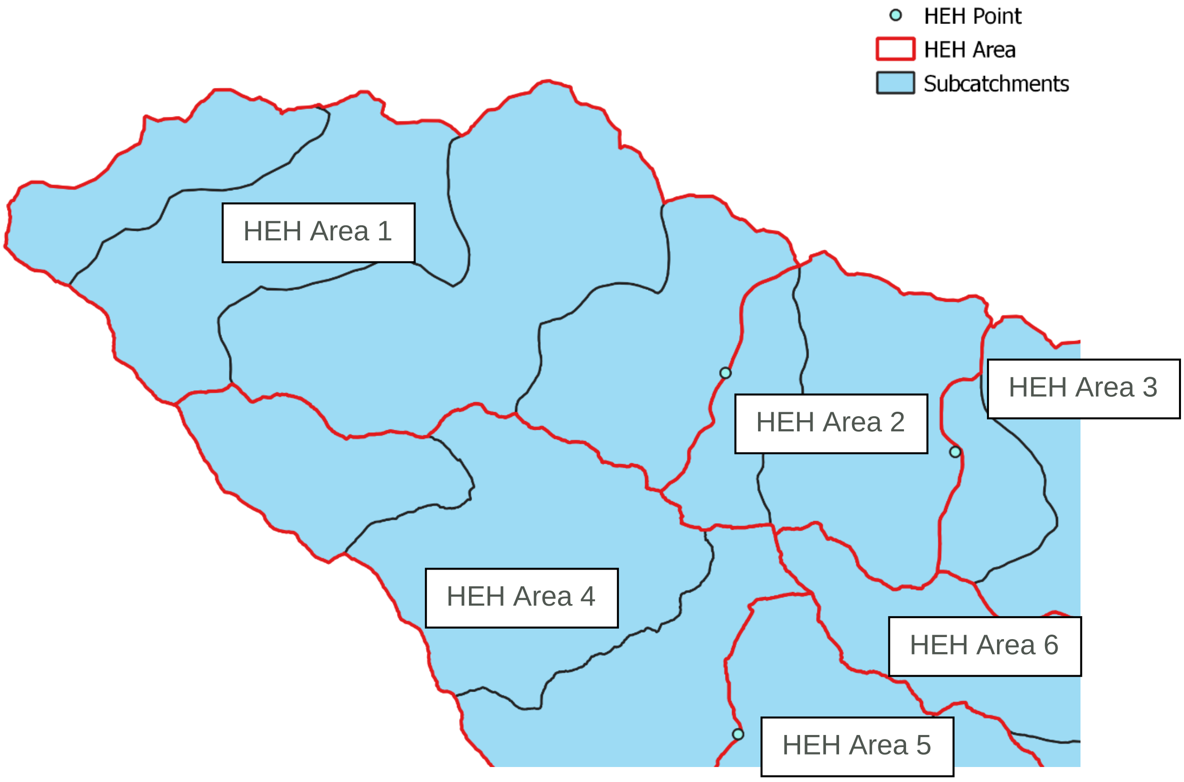


Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

The remainder of this Technical Note includes the following sections:

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

# Definitions

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

# Specifications

## Model simulations

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

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

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

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

## Identification of artificial storages at HEH point

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

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

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

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

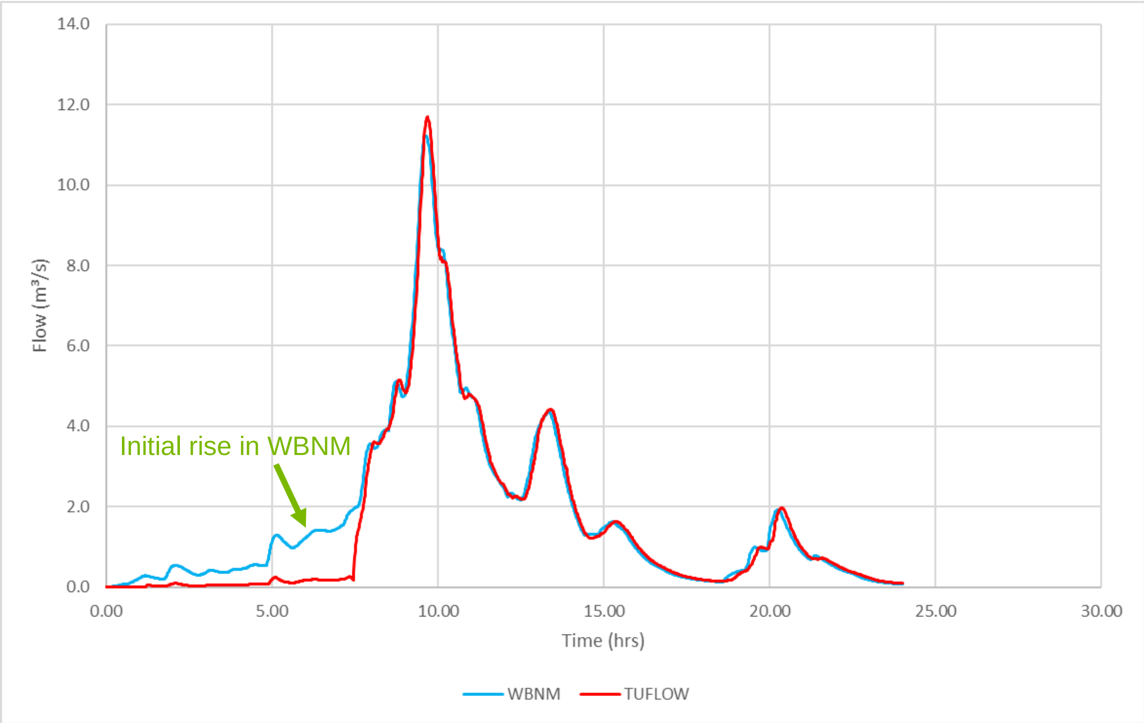


Figure 1.2 Example of the initial rise occurring in WBNM prior to TUFLOW

## Criteria for ‘matching’ the hydrographs at each HEH point

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

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

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

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

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

## Detailed Steps

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

### Flowchart

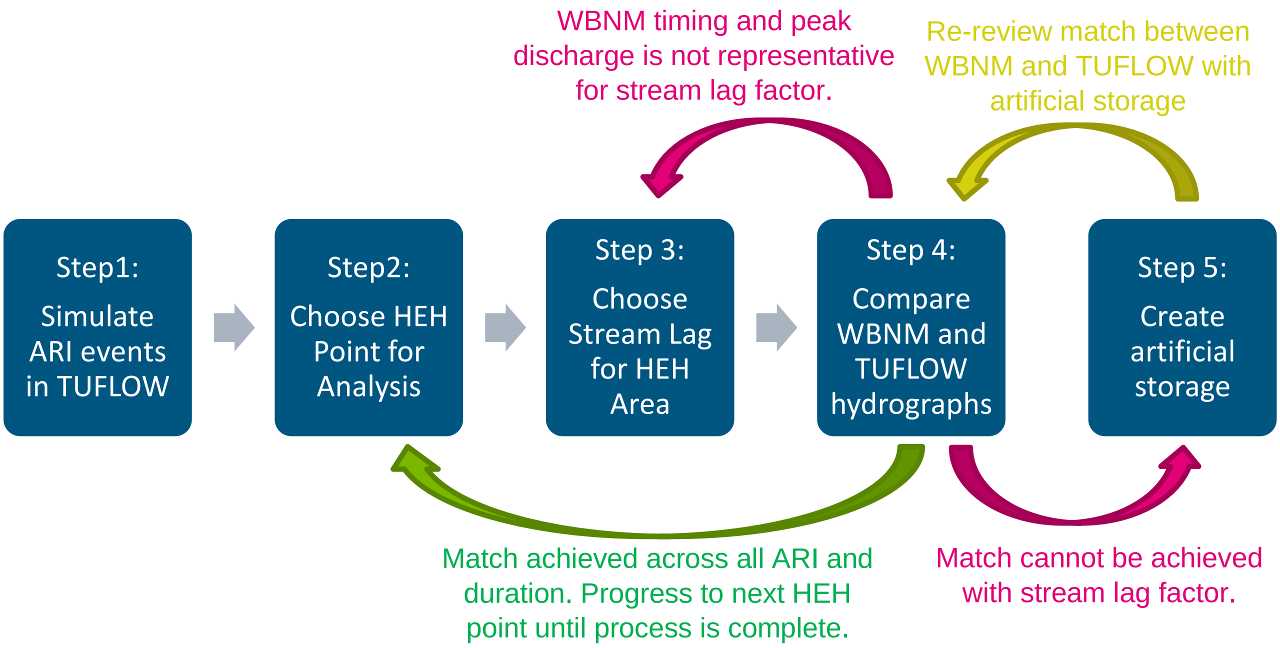


Figure 1.3 Flow chart for the HEH model methodology

### Step 1: Simulate ARI events in TUFLOW

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

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

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

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

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

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

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

### Step 4: Compare against TUFLOW hydrograph

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

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

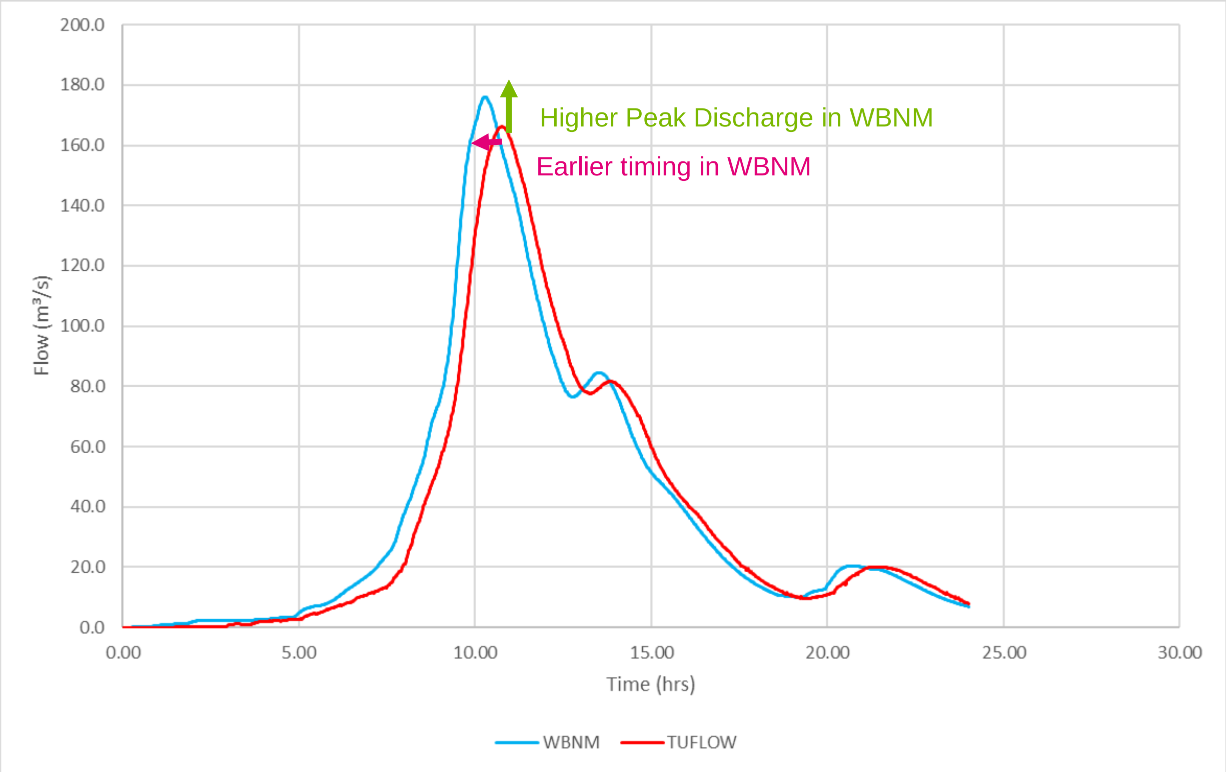


Figure 1.4 Ideal WBNM hydrograph for application of artificial storage

### Step 5: Create an artificial storage

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

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

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

#### Develop the Storage-Outflow table

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.

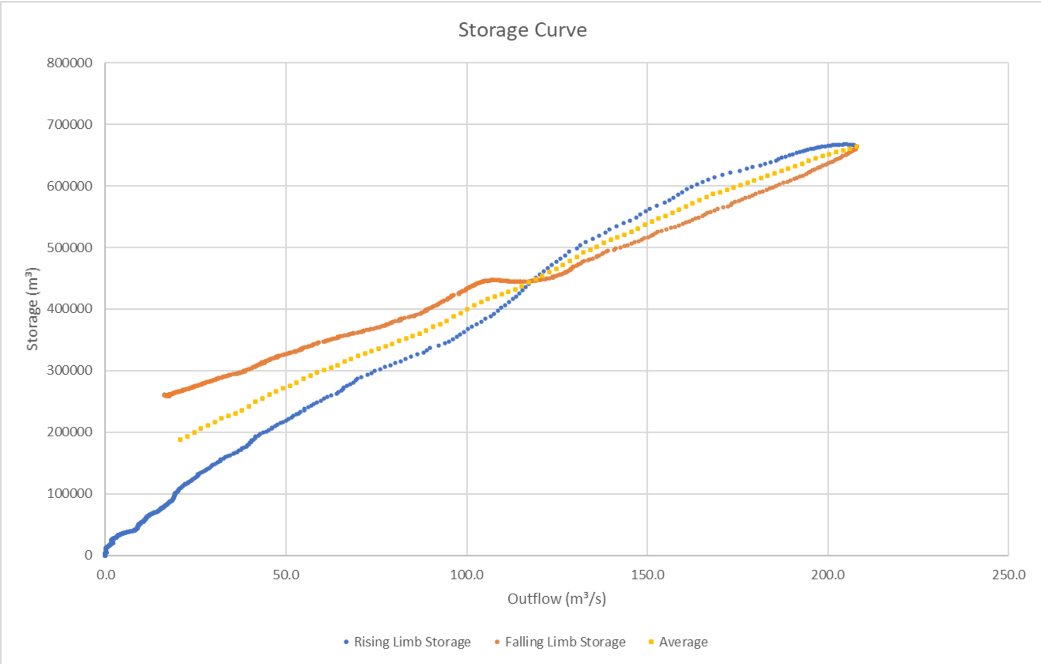


Figure 1.6 Ideal Storage-Outflow Curve

Light green dots result in
a curve which is not ideal

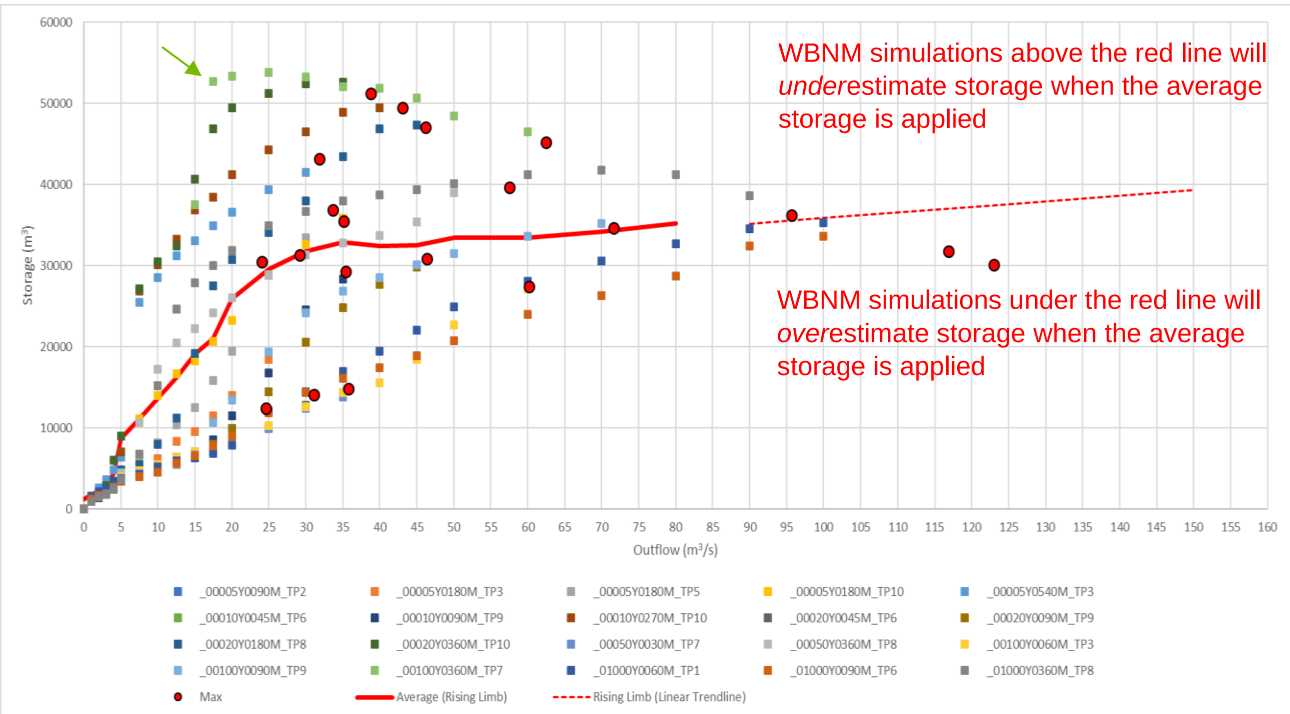


Figure 1.7 Example of an averaged S-Q curve (storages extracted from the rising limb of each duration and ARI)

### 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.

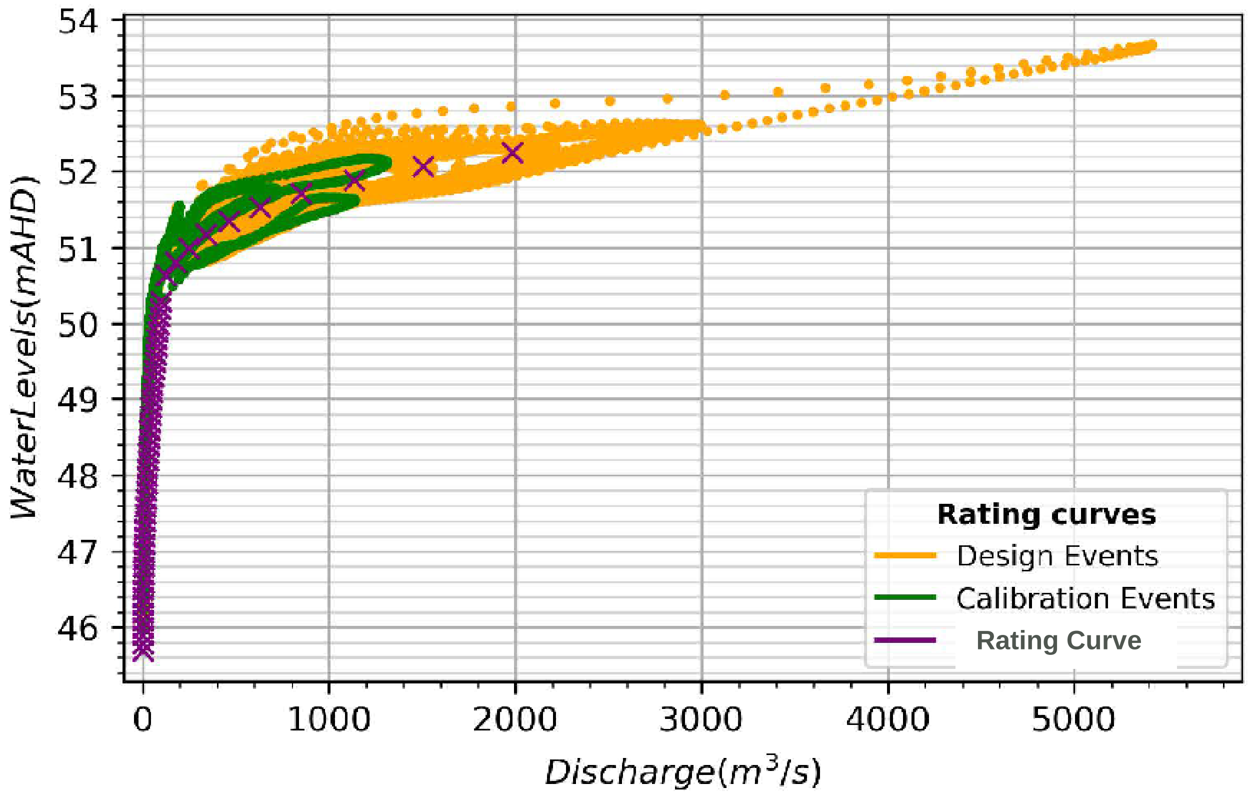


Figure 1.8 Rating curve with hysteresis

### 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 Upper Pine River HEH Modelling and Results

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# Draft Technical Note

| | | | |
|---|---|---|---|
| Project | A11567 – RFD 2021 Major Update | | |
| From: | Blair Filer | | |
| Date: | 13/02/2023 | To: | Hester van Zijl (MBRC) |
| Doc Ref: | T.A11567.013 | | |
| Subject: | Upper Pine River HEH Modelling and Results | | |

## Overview

This Technical Note has been prepared to outline the implementation and results for the Upper Pine River (UPR) 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. Details of the adopted HEH methodology are 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 defined '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 Note 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.

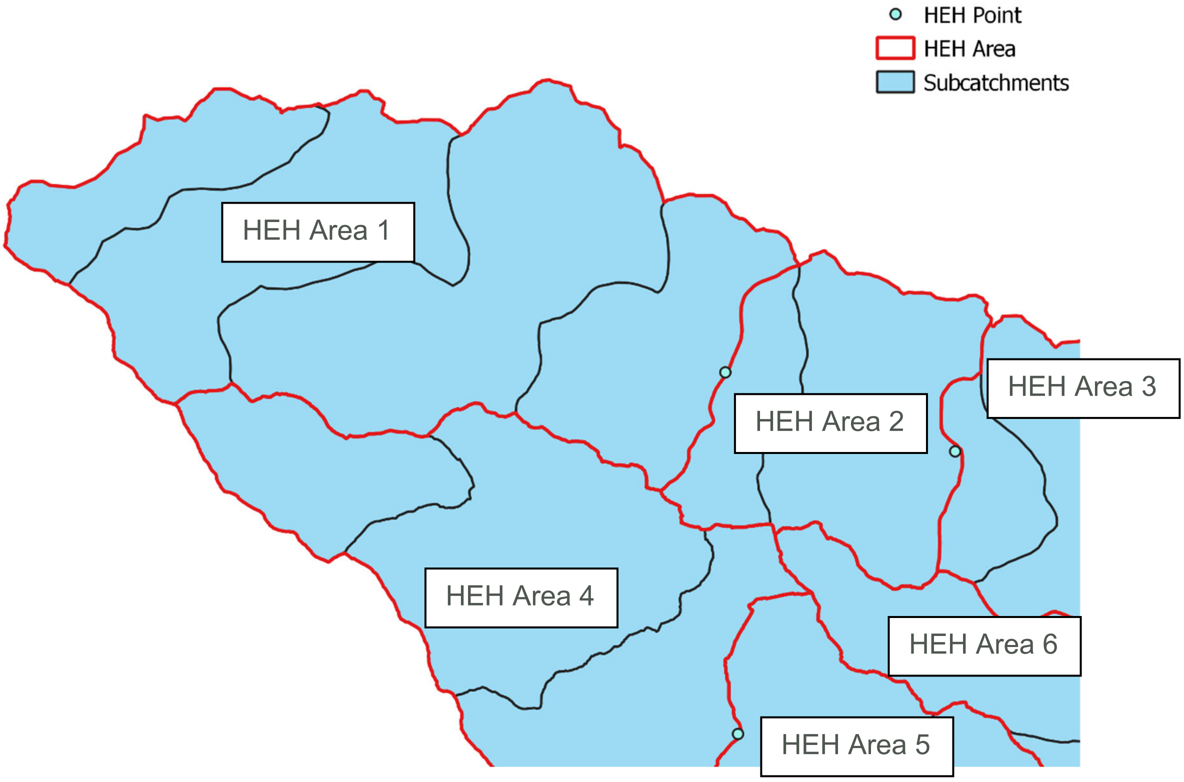



Figure 1.1 Layout of sub-catchments, HEH Points and HEH areas

## 1.2 Definitions

The definitions 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 Recurrence 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 as follows:

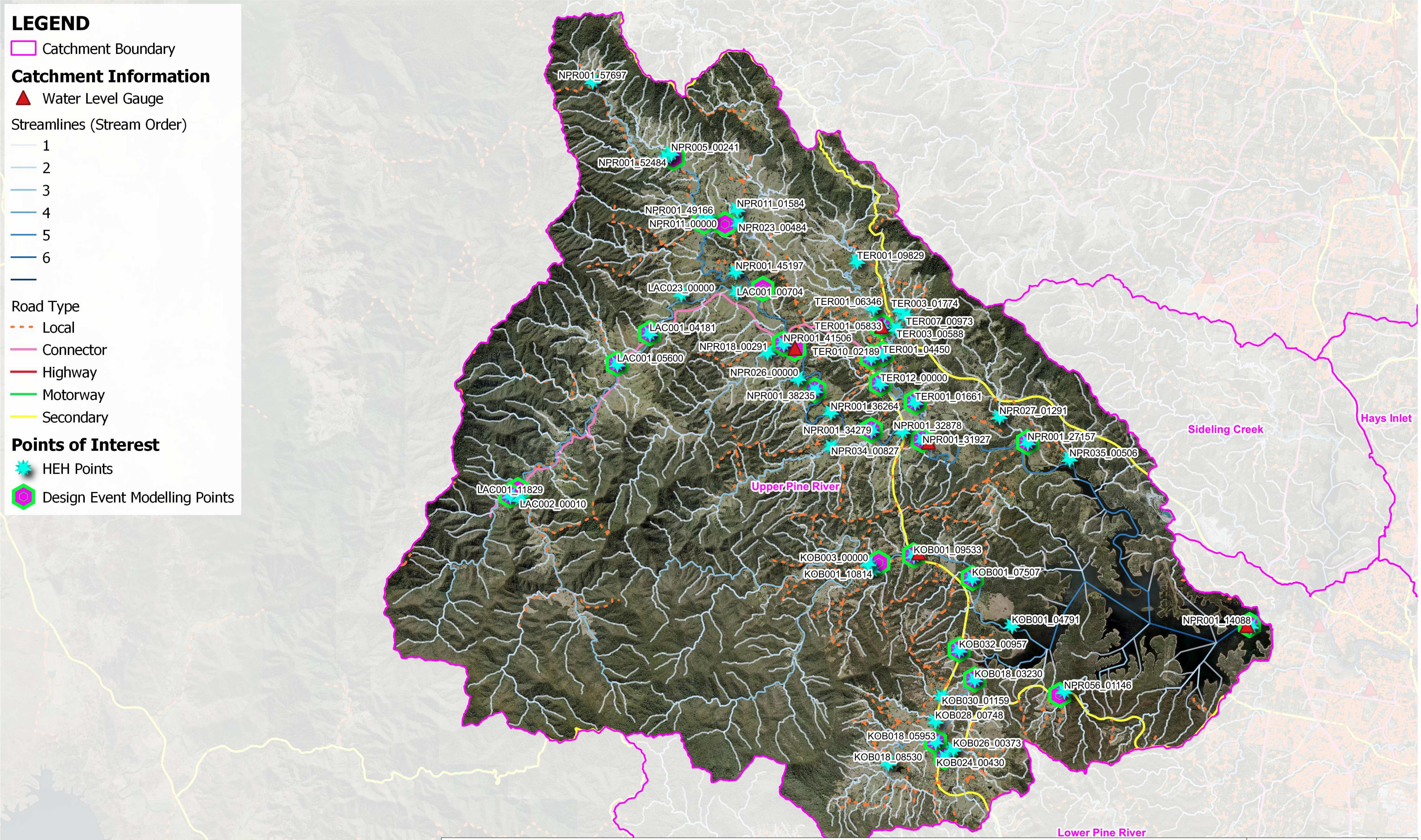
- HEH points –
  - Confluences – the points are located in each respective tributary (i.e. upstream of the confluence). Matching flow within each respective tributary allows the flow at the downstream confluence to be modelled more accurately.
  - Rural Areas – the points are located at local roads which cross significant streams in rural areas.
  - General – HEH points are not established within two sub-catchments of one-another. The underlining assumption is that the timing and peak discharge will not significantly change within two downstream 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 3 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 the Upper Pine River minor basin, 50 HEH points[1] and 29 Design Event Modelling points were created (64 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 127 undocumented points were reviewed for UPR.




Title:

**Points of Interest**

Figure: 2-1

Rev: A



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0 2,000 4,000 m

BMT

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# 3 HEH Implementation

## 3.1 Further Details to Framework

Further specific details regarding the steps involved in the implementation of the HEH methodology are summarised in Table 3.1.

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:<br>• ARI events– 5-year, 20-year, 100-year, 2000-year<br>• 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).<br>WBNM's 'delay' functionality was applied to the North Pine Dam with a 3-minute lag. The delay is a time translation of the hydrograph which excludes any channel storage. |
| 4 | The following was undertaken for comparison:<br>• The WBNM outputs were interpolated to match the TUFLOW output interval of 5-minutes.<br>• WBNM total flows at confluences were combined.<br>• At culvert locations, where TUFLOW contains both flow in 1D and 2D domains, the 1D and 2D flows were combined.<br>• 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 4.2. |
| 5 | The artificial storages were implemented based on the following:<br>• To apply an artificial storage at a confluence, 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.<br>• 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.<br>• The artificial storage was applied using either of the two methods below:<br>- 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.<br>- 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 Figure 3.2 where the blue dots are the extrapolation of the individual storage curves (from the orange dots) and the dashed lines |

| Step | Comment |
|---|---|
| | 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. |

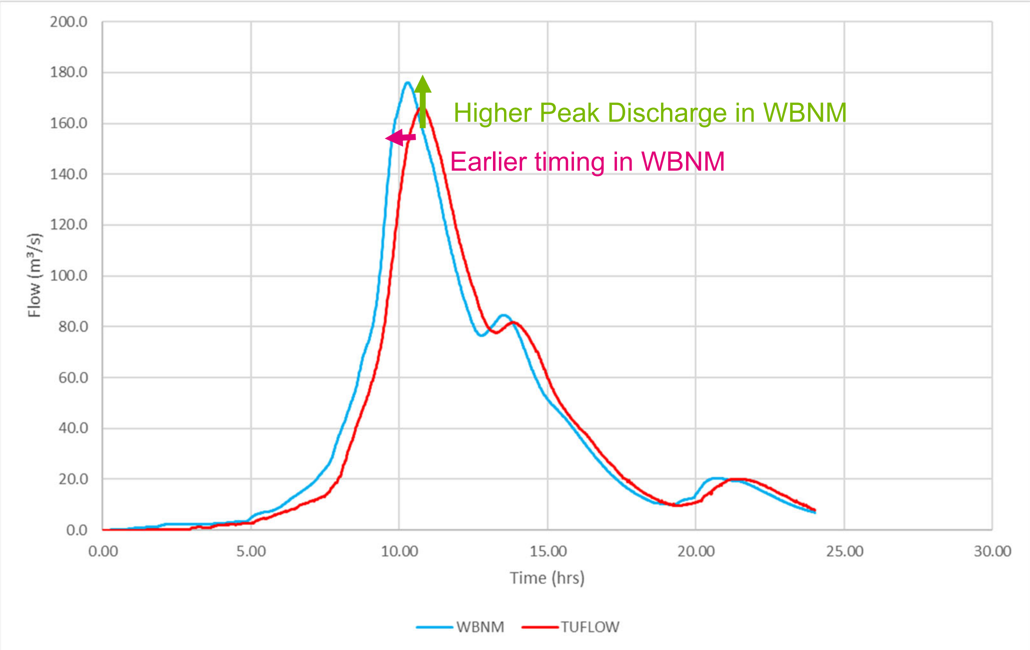



Figure 3.1 Ideal WBNM hydrograph for application of artificial storage

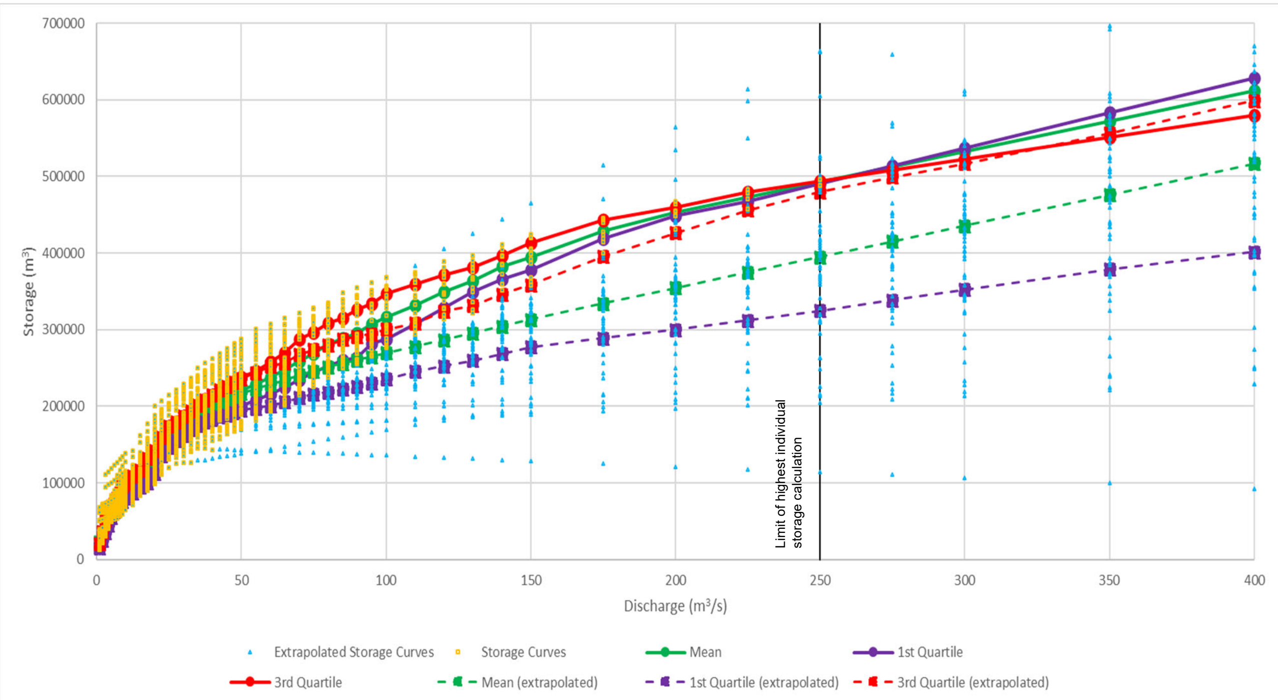



Figure 3.2 Statistical analysis for creating artificial storage curves

### 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 UPR 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 4.5.

In addition to the scores, 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_UPR.html”).

Figure 4.6, Figure 4.7, Figure 4.8, and Figure 4.9 present examples of the comparisons at HEH point ‘NPR001_14088’ 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 ‘NPR001_14088’ 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 UPR catchment, the following can be stated:

- The majority of HEH points have final scores that are considered either ‘good’ or ‘excellent’ with most of the HEH scores considered ‘excellent’. All scores are within the desired range (Section 4.2) except for the following:
  - HEH Point ‘TER010_02189’ has breakout flow in the TUFLOW results from TER001_04450 in the 100-year and 2000-year ARI resulting in a higher score as shown in Figure 4.1.

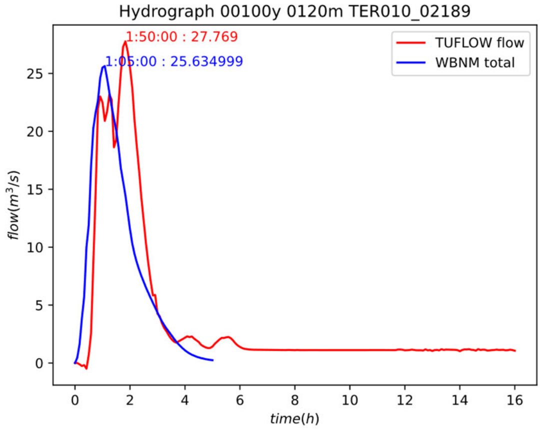



Figure 4.1 Breakout flow in TUFLOW results from TER001_04450

- HEH Point ‘NPR056_01146’ shows non uniform raising and falling shape due to the overtopping of the upstream road crossing. Figure 4.2 and the provided plots show that the HEH model mostly achieves the shape.

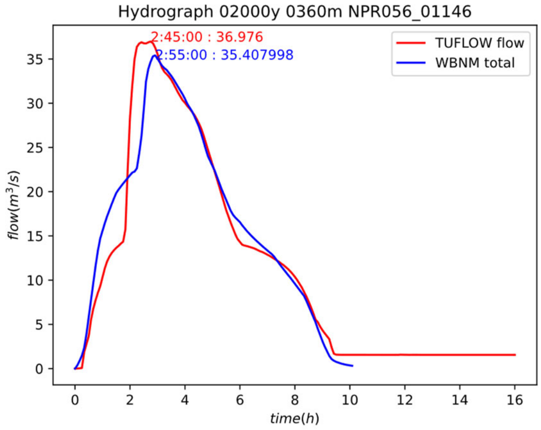



Figure 4.2 Overtopping at the upstream road creating a non-uniform shape in the TUFLOW results at NPR056_01146

- HEH Point ‘NPR026_00000’ is influenced by backwater from the main creek from the main creek creating double peaks in the TUFLOW, as shown in Figure 4.3. In most cases a negative peak is also experienced.

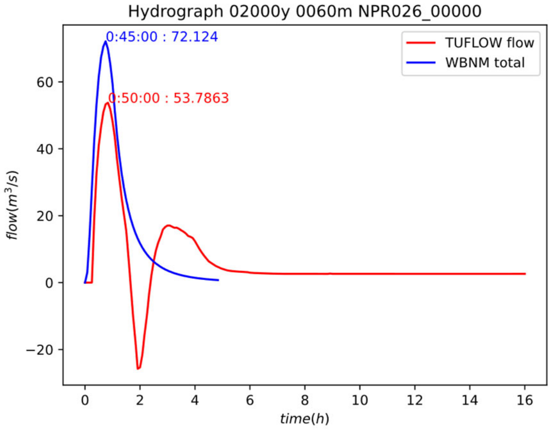



Figure 4.3 Backflow influence from the main creek in the TUFLOW results at NPR026_00000

- The outlet of the real detention basins does not align with the sub-catchment for the 'KOB028_00748' HEH Point. This affects the storage calculations at these points as there are double peaks in the TUFLOW results cannot be well replicated due to this inefficiency. This is as shown in shown in Figure 4.4.

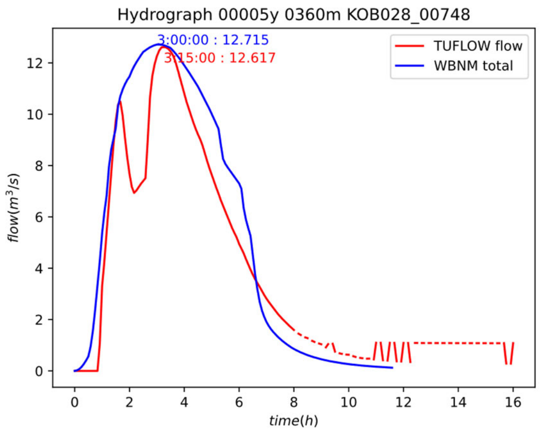



Figure 4.4 KOB028_00748 double peak of the TUFLOW due to sub-catchment outlet not at the outlet of the storage

- The timing of the peak discharge in Lake Samsonvale affects the score for HEH Point 'NPR001_14088'. Given that this is a downstream location within the model, and the modelled hydrograph shapes show a very good match this is considered a good result.

- In general, the stream lag factors are lower at the top of the catchment and become larger downstream. Given the interaction of multiple reaches to the waterbody of North Pine Dam (Lake Samsonvale) a delay was required to achieve the ideal hydrographs at the dam outlet. It would also be expected that the flood wave would travel faster than in normal reaches within this waterbody.

- Storages at road crossings typically required more storage to achieve a match to the TUFLOW result at higher flows, hence the 3rd quartile was used rather than the mean.

- The dummy sub-catchment ‘TER010_03DUM’ has been included to implement the artificial storage within the ‘TER010_02189’ HEH area. Four additional dummy sub-catchments have also been included at confluences for the ‘design event modelling’ points.

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) |
|---|---|---|---|---|
| TER012_00000 | 0.85 | | | 18.2 |
| TER010_02189 | 0.20 | ✓ | Mean | 75.2[1] (177.7) |
| TER007_00973 | 1.10 | | | 20.8 |
| TER003_01774 | 0.50 | | | 10.5 |
| TER003_00588 | 0.90 | | | 11.5 |
| TER001_09829 | 0.40 | | | 7.6 |
| TER001_06346 | 0.90 | | | 17.2 |
| TER001_05833 | 1.10 | | | 15.8 |
| TER001_04450 | 1.15 | ✓ | Mean | 10.6 (39.8) |
| TER001_01661 | 1.05 | ✓ | Mean | 7.5 (38.0) |
| NPR056_01146 | 0.45 | ✓ | Mean | 69.5[1] (323.7) |
| NPR035_00506 | 0.30 | ✓ | Mean | 29.8 (48.4) |
| NPR034_00827 | 0.35 | | | 16.0 |
| NPR027_01291 | 0.85 | | | 8.7 |
| NPR026_00000 | 0.20[2] | | | 94.1 |
| NPR023_00484 | 0.85 | | | 21.3 |
| NPR018_00291 | 0.30 | | | 13.0 |
| NPR011_01584 | 0.45 | | | 9.7 |
| NPR011_00000 | 1.15 | | | 5.6 |
| NPR005_00241 | 0.45 | | | 3.0 |
| NPR001_57697 | 0.30 | | | 9.5 |
| NPR001_52484 | 0.45 | | | 16.0 |
| NPR001_49166 | 0.70 | | | 12.8 |
| NPR001_45197 | 1.00 | | | 11.0 |
| NPR001_41506 | 1.05 | | | 4.8 |
| NPR001_38235 | 1.25 | | | 7.3 |
| NPR001_34279 | 1.25 | | | 6.3 |

| HEH Point Name | Adopted Stream Lag Factor | Artificial Storage Included | Artificial Storage Calculation Method | Final Score (Score without Artificial Storage) |
|---|---|---|---|---|
| NPR001_32878 | 1.25 | | | 12.1 |
| NPR001_31927 | 1.25 | ✓ | 3rd Quartile | 11.5 (44.4) |
| NPR001_27157 | 1.25 | | | 20.5 |
| NPR001_14088 | 3-minute | ✓ | Mean (Extrapolated) | 42.9 (126.2) |
| LAC023_00000 | 0.35 | | | 14.0 |
| LAC002_00010 | 0.30 | | | 13.9 |
| LAC001_11829 | 0.30 | | | 11.9 |
| LAC001_05600 | 0.55 | | | 8.7 |
| LAC001_04181 | 0.85 | | | 8.1 |
| LAC001_00704 | 1.00 | | | 7.2 |
| KOB032_00957 | 0.50 | ✓ | 3rd Quartile | 13.7 (249.5) |
| KOB030_01159 | 0.50 | | | 8.9 |
| KOB028_00748 | 0.35 | ✓ | 3rd Quartile | 40.2[1] (150.1) |
| KOB026_00373 | 1.00 | | | 17.9 |
| KOB024_00430 | 0.90 | | | 15.8 |
| KOB018_08530 | 0.60 | | | 5.7 |
| KOB018_05953 | 0.70 | ✓ | Mean | 14.2 (69.7) |
| KOB018_03230 | 0.85 | | | 22.0 |
| KOB003_00000 | 0.45 | | | 18.3 |
| KOB001_10814 | 0.35 | | | 18.5 |
| KOB001_09533 | 0.70 | | | 13.3 |
| KOB001_07507 | 0.45 | | | 14.5 |
| KOB001_04791 | 3-minute | | | 17.1 |

**1 Storage moved to an upstream sub-catchment.**

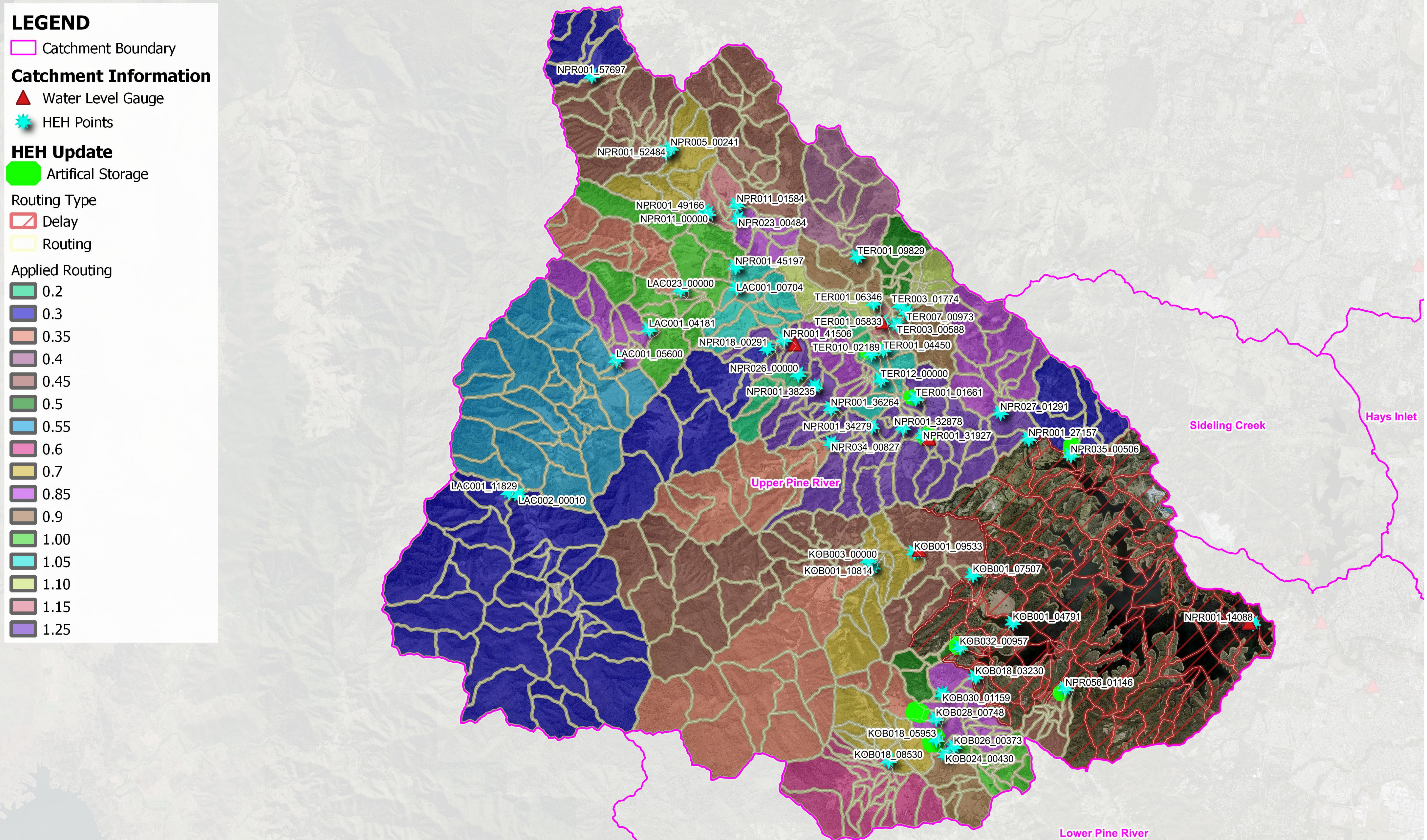
**2 TUFLOW results being affected by the creek floodplain causing double peaks, best timing was applied.**

## 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) |
|---|---|---|---|
| TER012_00000 | 0.95 (0.91) | 4.0 (7.0) | 9.6 (30) |
| TER010_02189 | 0.64 (0.35) | 17.8 (62.2) | 21.7 (50) |

| HEH Point Name | Average (Lowest) Nash-Sutcliffe Efficiency | Average (Largest) Peak Ratio (%) | Average (Largest) Difference in Timing (minutes) |
|---|---|---|---|
| TER007_00973 | 0.90 (0.76) | 6.9 (16.6) | 3.8 (5) |
| TER003_01774 | 0.95 (0.87) | 2.9 (5.7) | 2.9 (5) |
| TER003_00588 | 0.94 (0.87) | 2.9 (13) | 2.9 (10) |
| TER001_09829 | 0.99 (0.98) | 3.0 (4.8) | 3.8 (25) |
| TER001_06346 | 0.96 (0.93) | 6.6 (10.8) | 6.7 (10) |
| TER001_05833 | 0.97 (0.94) | 6.3 (11.8) | 6.3 (10) |
| TER001_04450 | 0.99 (0.97) | 5.7 (18.2) | 3.8 (10) |
| TER001_01661 | 0.99 (0.97) | 3.7 (7.7) | 2.5 (10) |
| NPR056_01146 | 0.90 (0.78) | 14.9 (26.9) | 44.2 (115) |
| NPR035_00506 | 0.90 (0.79) | 6.9 (19.6) | 13.3 (40) |
| NPR034_00827 | 0.96 (0.92) | 5.3 (8.9) | 6.3 (15) |
| NPR027_01291 | 0.98 (0.98) | 3.2 (6.5) | 3.8 (5) |
| NPR026_00000 | 0.45 (0.09) | 33.7 (37.1) | 5.8 (10) |
| NPR023_00484 | 0.91 (0.82) | 4.5 (16.3) | 7.5 (15) |
| NPR018_00291 | 0.96 (0.93) | 2.3 (11.9) | 6.7 (25) |
| NPR011_01584 | 0.97 (0.96) | 3.6 (8.1) | 3.3 (10) |
| NPR011_00000 | 0.99 (0.98) | 1.4 (5) | 3.3 (5) |
| NPR005_00241 | 0.99 (0.96) | 0.7 (1.4) | 0.8 (5) |
| NPR001_57697 | 0.97 (0.92) | 1.6 (3.5) | 4.6 (5) |
| NPR001_52484 | 0.93 (0.87) | 3.2 (7.4) | 5.8 (10) |
| NPR001_49166 | 0.97 (0.94) | 6.0 (8.5) | 3.8 (10) |
| NPR001_45197 | 0.96 (0.92) | 4.4 (7.4) | 2.9 (10) |
| NPR001_41506 | 0.99 (0.98) | 1.1 (1.8) | 2.9 (5) |
| NPR001_38235 | 0.98 (0.98) | 1.2 (3.1) | 4.6 (10) |
| NPR001_34279 | 0.99 (0.97) | 1.8 (5.7) | 3.3 (10) |
| NPR001_32878 | 0.98 (0.96) | 2.6 (6.3) | 7.5 (10) |
| NPR001_31927 | 0.99 (0.97) | 5.4 (11.4) | 4.6 (10) |
| NPR001_27157 | 0.96 (0.93) | 10.1 (17) | 6.7 (15) |
| NPR001_14088 | 0.95 (0.89) | 5.8 (8.8) | 31.7 (45) |
| LAC023_00000 | 0.96 (0.91) | 5.6 (9.1) | 4.6 (25) |
| LAC002_00010 | 0.95 (0.93) | 4.7 (14.7) | 4.2 (10) |
| LAC001_11829 | 0.97 (0.96) | 4.9 (9.8) | 4.2 (10) |

| HEH Point Name | Average (Lowest) Nash-Sutcliffe Efficiency | Average (Largest) Peak Ratio (%) | Average (Largest) Difference in Timing (minutes) |
|---|---|---|---|
| LAC001_05600 | 0.99 (0.98) | 4.0 (8.6) | 3.8 (10) |
| LAC001_04181 | 0.99 (0.99) | 3.7 (7.7) | 3.8 (10) |
| LAC001_00704 | 0.99 (0.97) | 3.0 (5.8) | 3.3 (10) |
| KOB032_00957 | 0.96 (0.89) | 5.3 (18.9) | 4.2 (20) |
| KOB030_01159 | 0.97 (0.93) | 2.8 (5.1) | 3.3 (5) |
| KOB028_00748 | 0.84 (0.48) | 8.4 (29.8) | 16.3 (35) |
| KOB026_00373 | 0.92 (0.86) | 6.4 (13.3) | 3.8 (10) |
| KOB024_00430 | 0.96 (0.94) | 5.6 (17.6) | 5.8 (25) |
| KOB018_08530 | 1.00 (0.99) | 3.6 (6.7) | 1.7 (5) |
| KOB018_05953 | 0.98 (0.97) | 3.2 (7.2) | 9.2 (30) |
| KOB018_03230 | 0.96 (0.94) | 6.3 (10.6) | 11.7 (25) |
| KOB003_00000 | 0.95 (0.92) | 5.2 (9.8) | 8.3 (15) |
| KOB001_10814 | 0.92 (0.87) | 4.2 (8.0) | 6.7 (10) |
| KOB001_09533 | 0.97 (0.96) | 4.1 (9.4) | 6.7 (15) |
| KOB001_07507 | 0.97 (0.94) | 5.1 (10.4) | 6.3 (15) |
| KOB001_04791 | 0.93 (0.9) | 3.7 (10.0) | 6.7 (10) |

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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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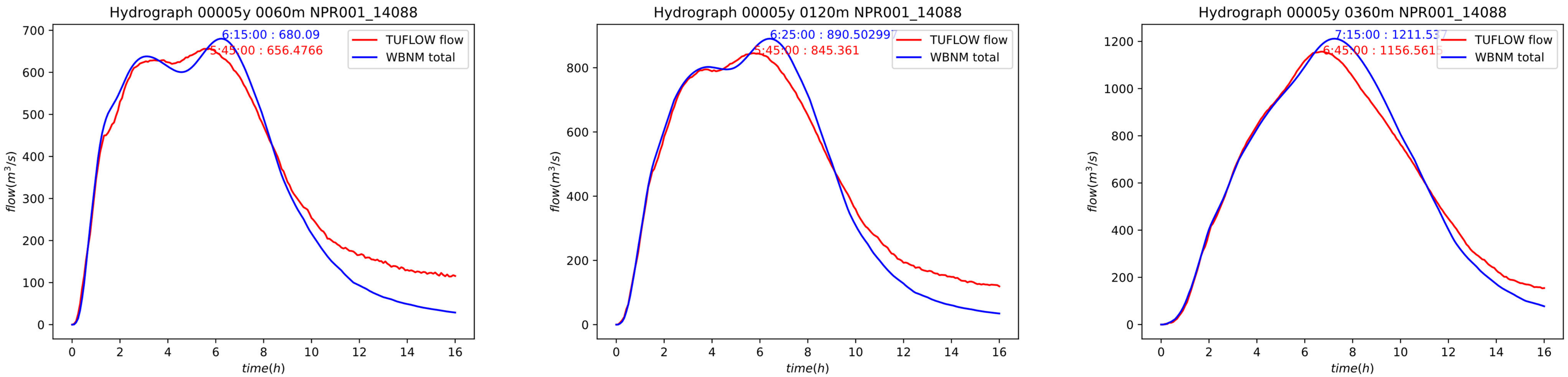



Figure 4.6 NPR001_14088 for the 5-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

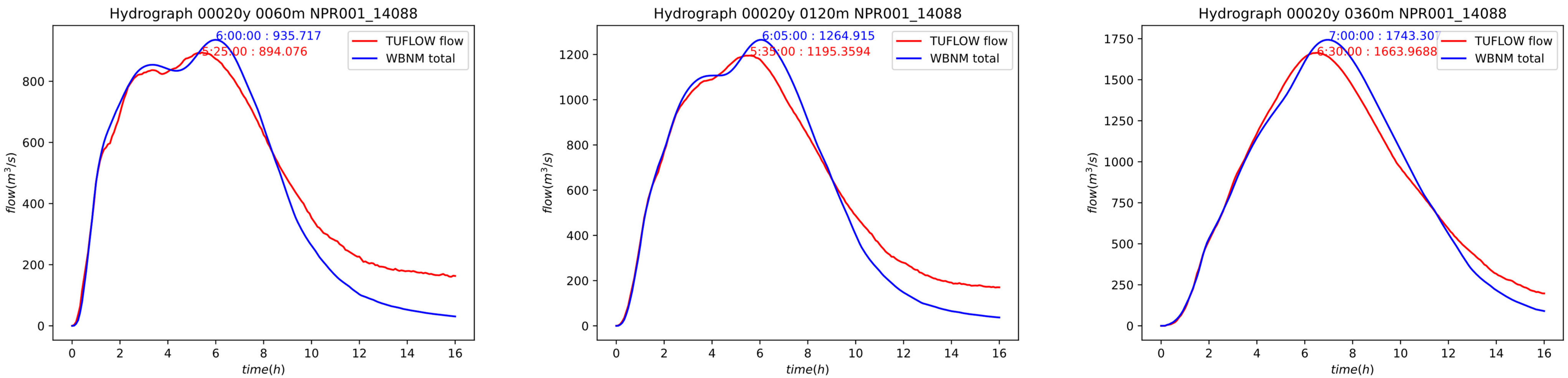



Figure 4.7 NPR001_14088 for the 20-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

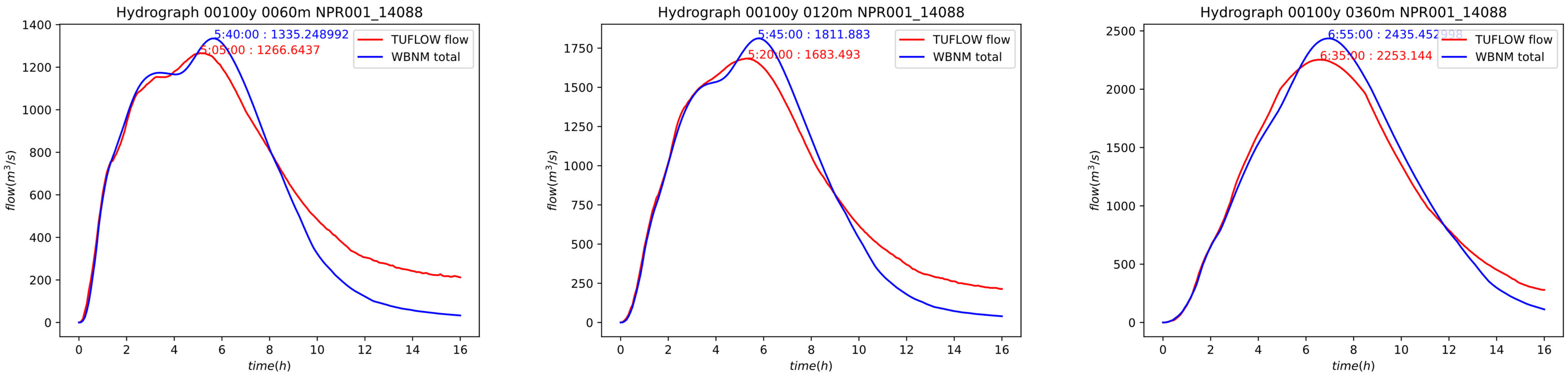



Figure 4.8 NPR001_14088 for the 100-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

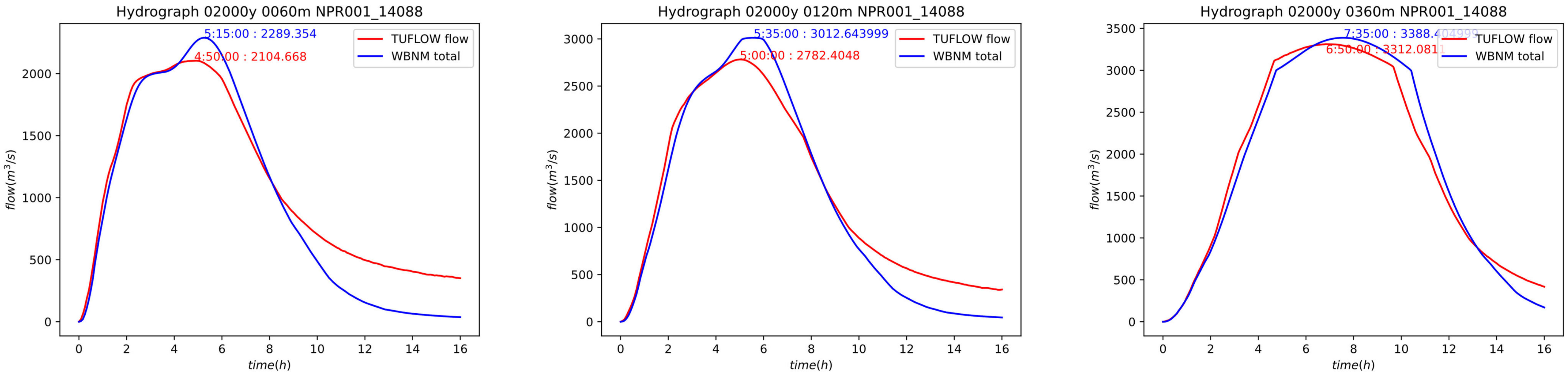


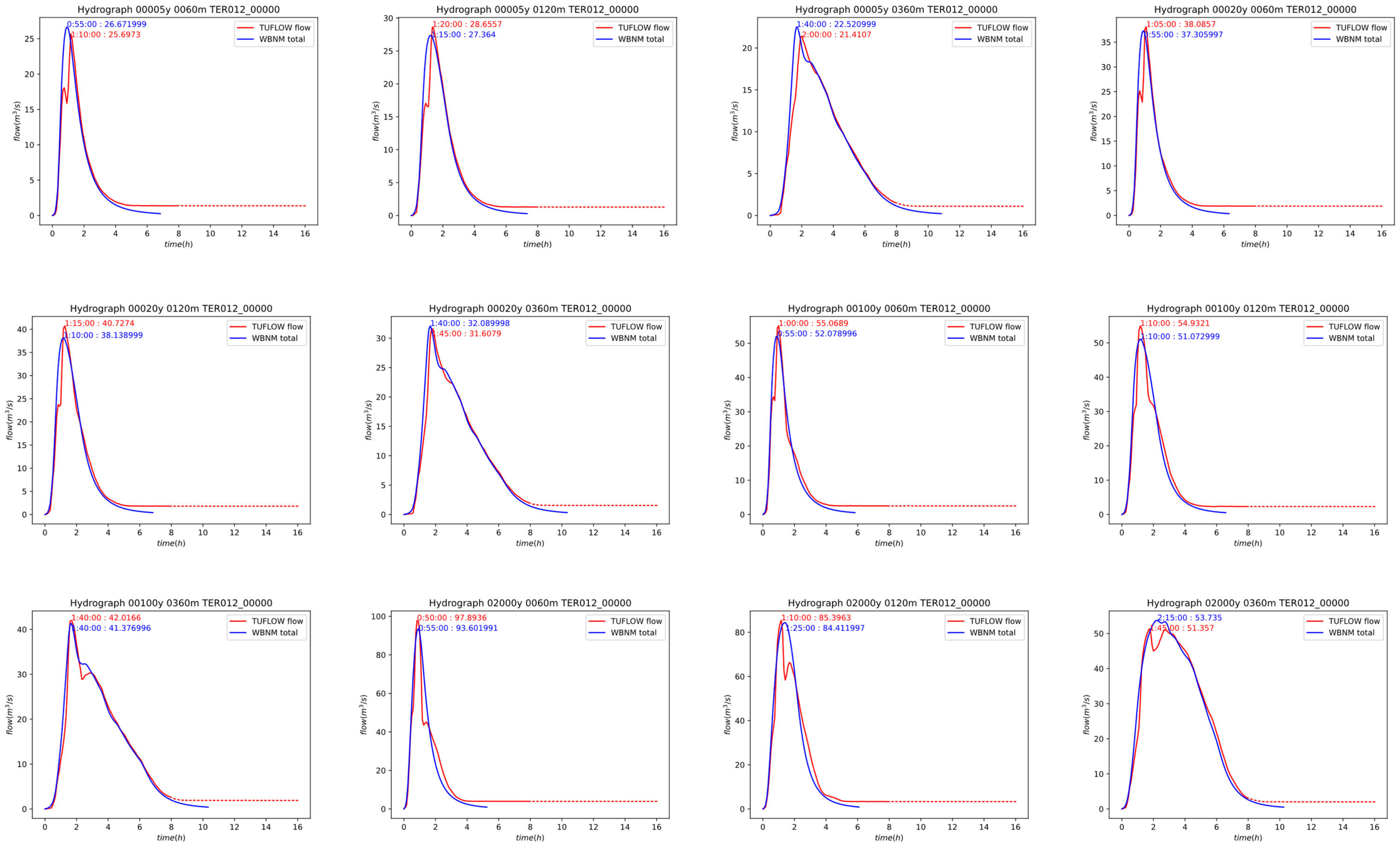

Figure 4.9 NPR001_14088 for the 2000-year ARI (left is 60-minute duration, middle is 120-minute duration, right is 360-minute duration)

Table 4.3 Criteria for all ARI Events and Duration for NPR001_14088

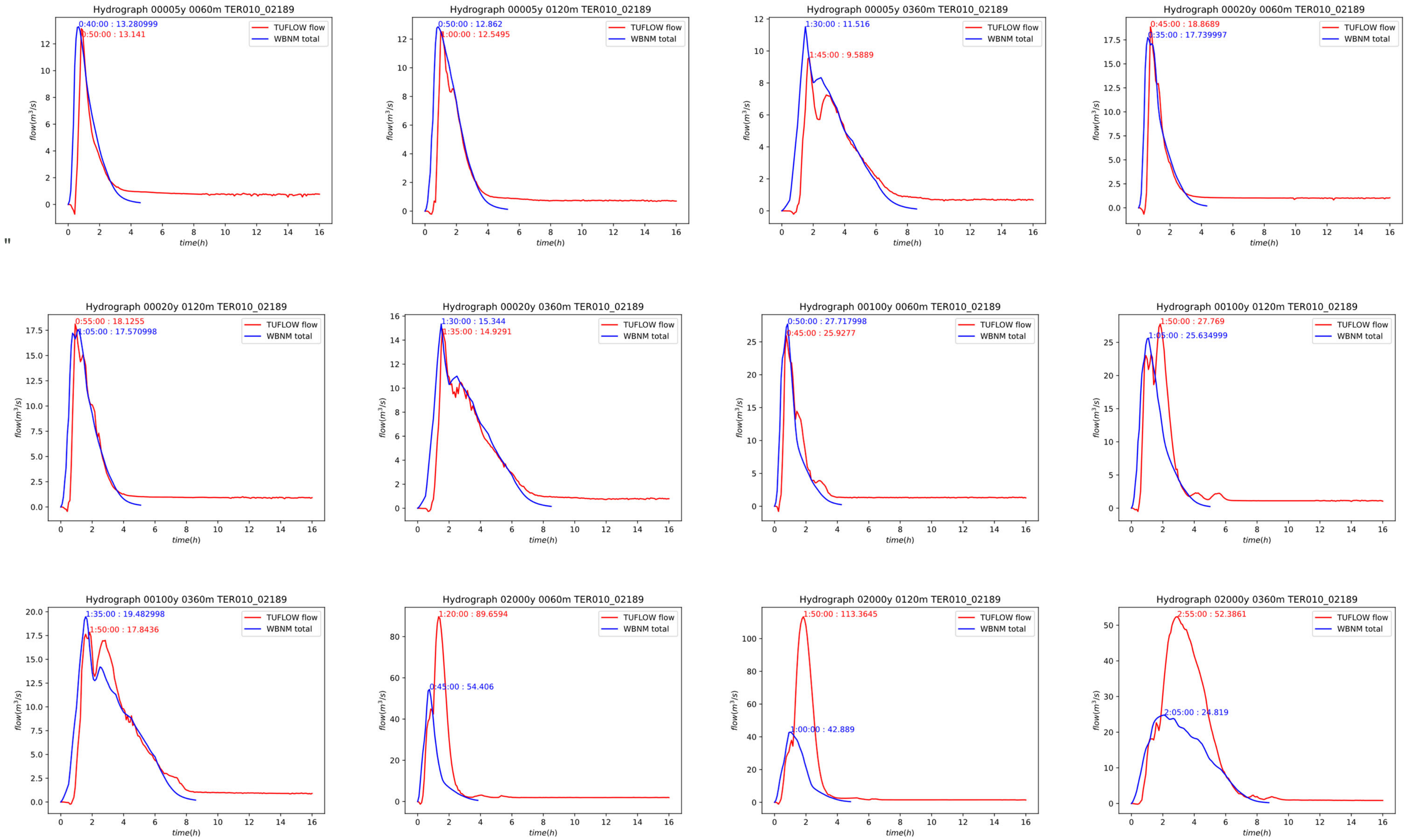
| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | 3.6 | 30.0 |
| 5-year 120-minute | 0.96 | 5.3 | 40.0 |
| 5-year 360-minute | 0.98 | 4.8 | 30.0 |
| 20-year 60-minute | 0.92 | 4.7 | 35.0 |
| 20-year 120-minute | 0.95 | 5.8 | 30.0 |
| 20-year 360-minute | 0.97 | 4.8 | 30.0 |
| 100-year 60-minute | 0.90 | 5.4 | 35.0 |
| 100-year 120-minute | 0.94 | 7.6 | 25.0 |
| 100-year 360-minute | 0.98 | 8.1 | 20.0 |
| 2000-year 60-minute | 0.89 | 8.8 | 25.0 |
| 2000-year 120-minute | 0.94 | 8.3 | 35.0 |
| 2000-year 360-minute | 0.98 | 2.3 | 45.0 |

# Annex D Upper Pine River HEH Hydrographs

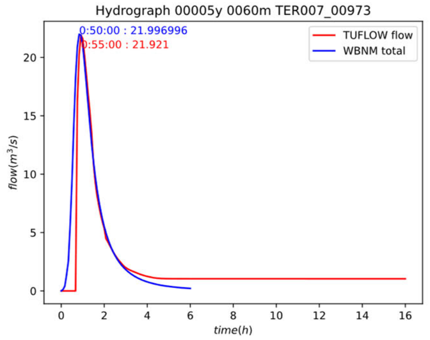
## Revision 11 (Existing Conditions)

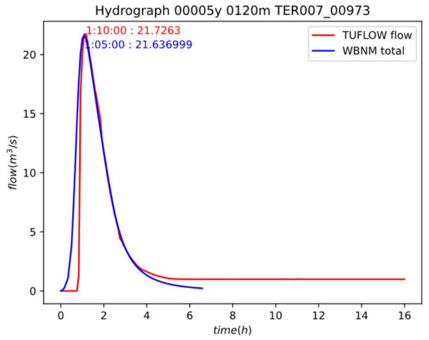


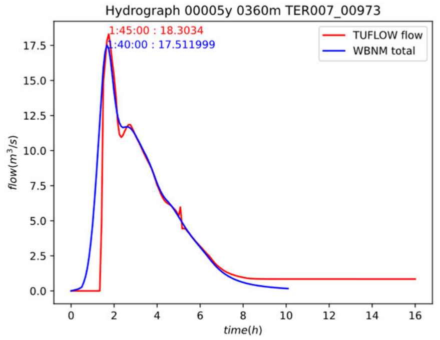

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.91 | 3.8 | -15.0 |
| 5-year 120-minute | 0.94 | -4.5 | -5.0 |
| 5-year 360-minute | 0.95 | 5.2 | -20.0 |
| 20-year 60-minute | 0.94 | -2.0 | -10.0 |
| 20-year 120-minute | 0.96 | -6.4 | -5.0 |
| 20-year 360-minute | 0.97 | 1.5 | -5.0 |
| 100-year 60-minute | 0.96 | -5.4 | -5.0 |
| 100-year 120-minute | 0.96 | -7.0 | 0.0 |
| 100-year 360-minute | 0.98 | -1.5 | 0.0 |
| 2000-year 60-minute | 0.93 | -4.4 | 5.0 |
| 2000-year 120-minute | 0.95 | -1.2 | 15.0 |
| 2000-year 360-minute | 0.98 | 4.6 | 30.0 |

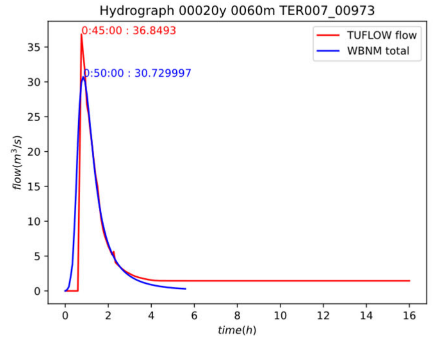


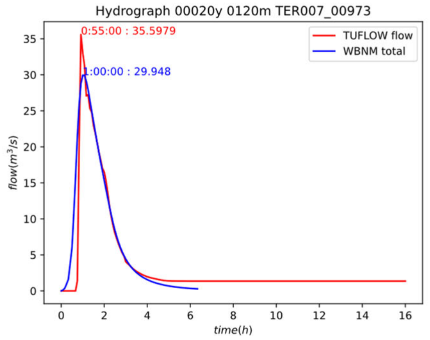

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.42 | 1.1 | -10.0 |
| 5-year 120-minute | 0.63 | 2.5 | -10.0 |
| 5-year 360-minute | 0.68 | 20.1 | -15.0 |
| 20-year 60-minute | 0.62 | -6.0 | -10.0 |
| 20-year 120-minute | 0.79 | -3.1 | 10.0 |
| 20-year 360-minute | 0.84 | 2.8 | -5.0 |
| 100-year 60-minute | 0.75 | 6.9 | 5.0 |
| 100-year 120-minute | 0.75 | -7.7 | -45.0 |
| 100-year 360-minute | 0.90 | 9.2 | -15.0 |
| 2000-year 60-minute | 0.35 | -39.3 | -35.0 |
| 2000-year 120-minute | 0.37 | -62.2 | -50.0 |
| 2000-year 360-minute | 0.61 | -52.6 | -50.0 |

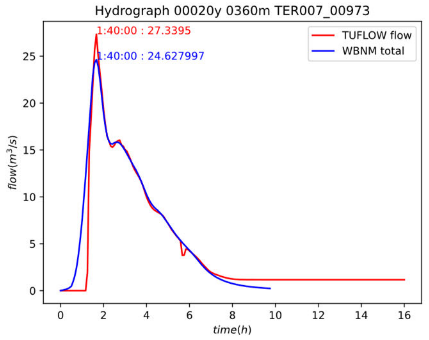


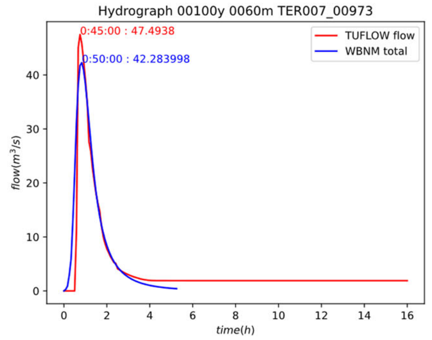



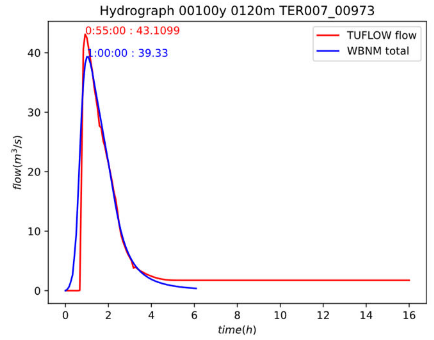



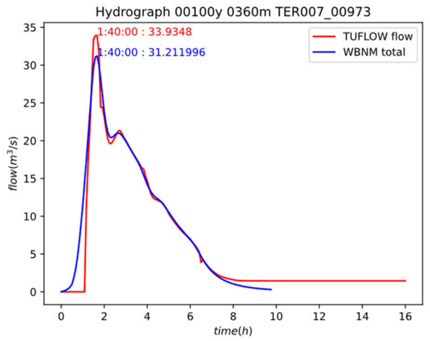



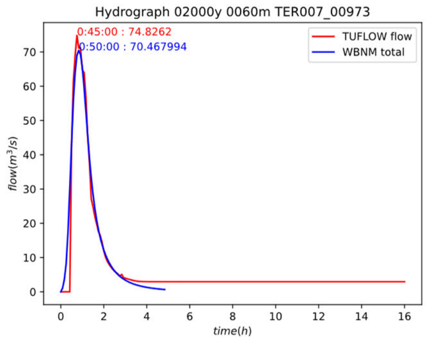



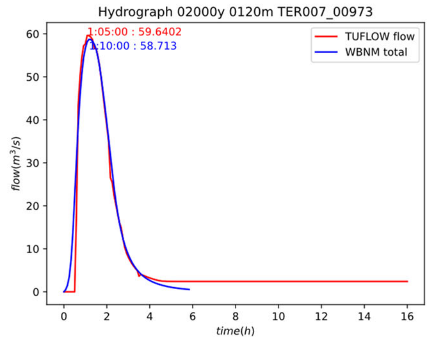



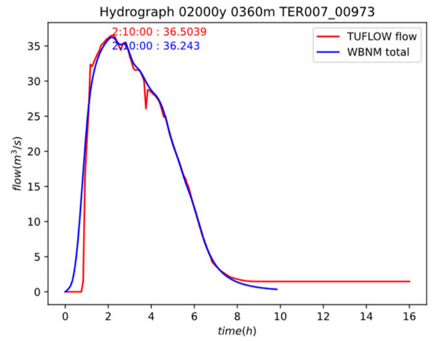



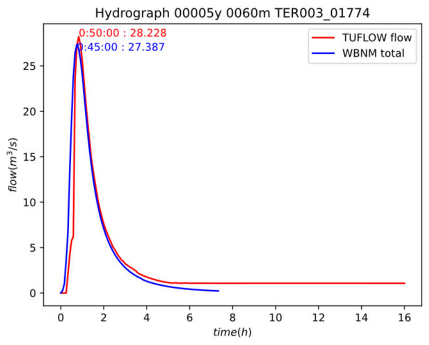



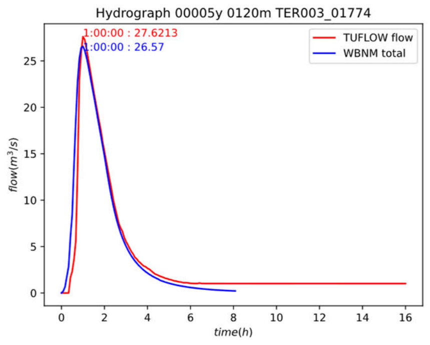



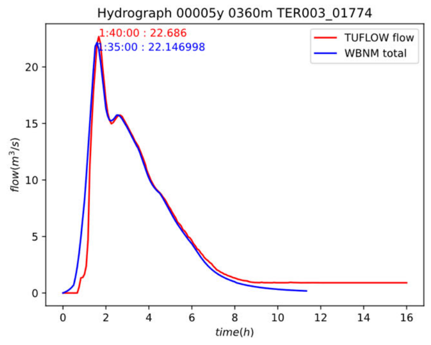



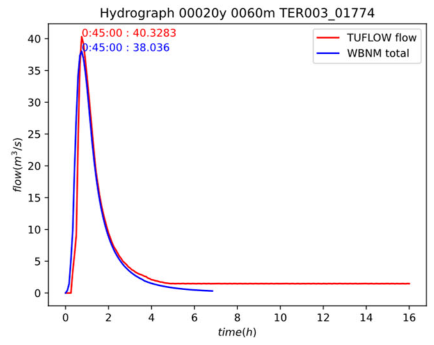



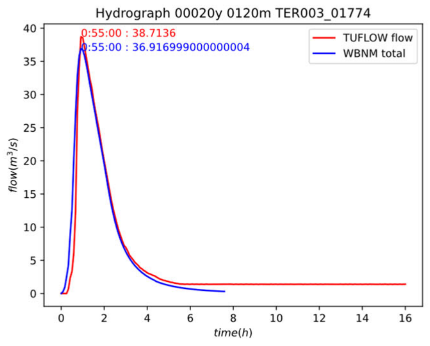

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.76 | 0.3 | -5.0 |
| 5-year 120-minute | 0.83 | -0.4 | -5.0 |
| 5-year 360-minute | 0.86 | -4.3 | -5.0 |
| 20-year 60-minute | 0.85 | -16.6 | 5.0 |
| 20-year 120-minute | 0.88 | -15.9 | 5.0 |
| 20-year 360-minute | 0.92 | -9.9 | 0.0 |
| 100-year 60-minute | 0.90 | -11.0 | 5.0 |
| 100-year 120-minute | 0.93 | -8.8 | 5.0 |
| 100-year 360-minute | 0.95 | -8.0 | 0.0 |
| 2000-year 60-minute | 0.96 | -5.8 | 5.0 |
| 2000-year 120-minute | 0.97 | -1.6 | 5.0 |
| 2000-year 360-minute | 0.98 | -0.7 | 0.0 |

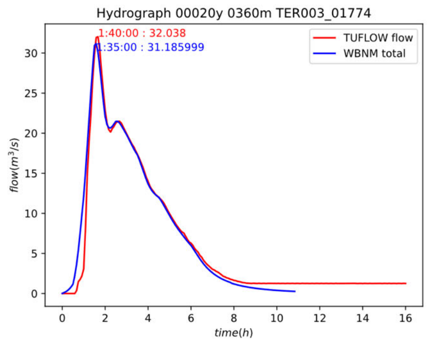


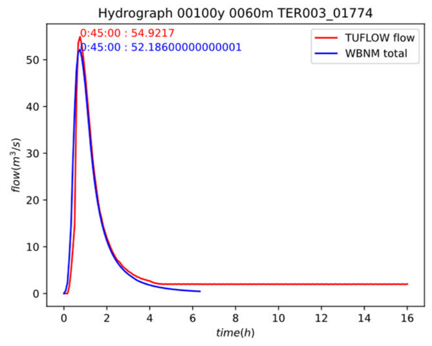



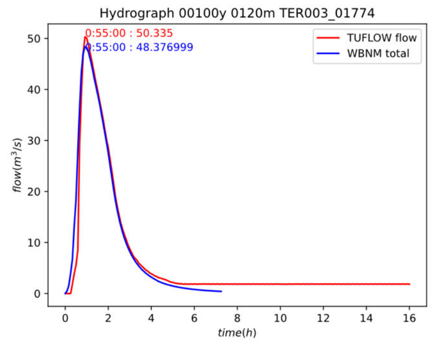



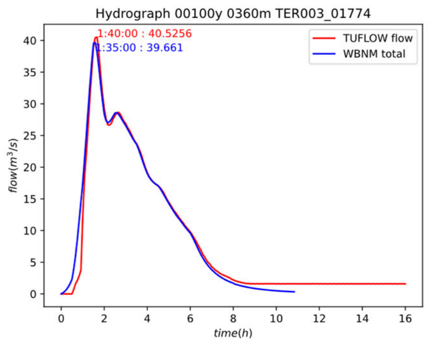



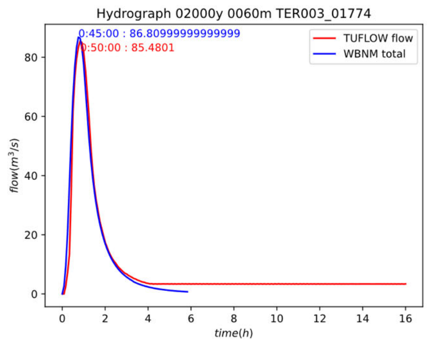



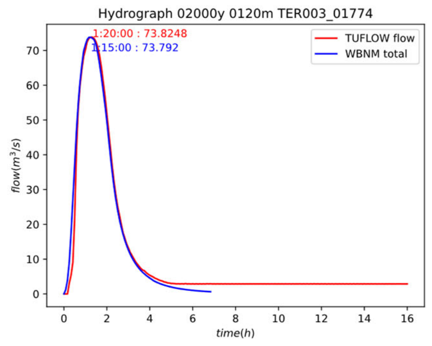



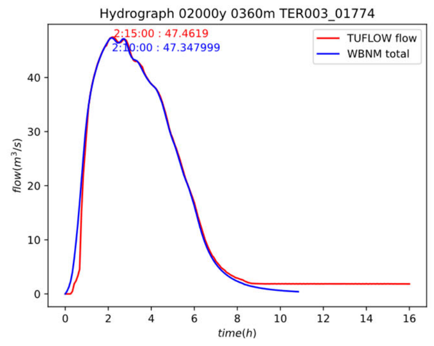



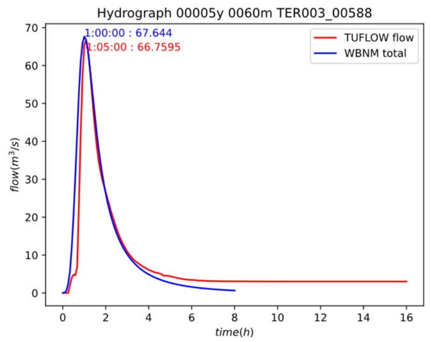



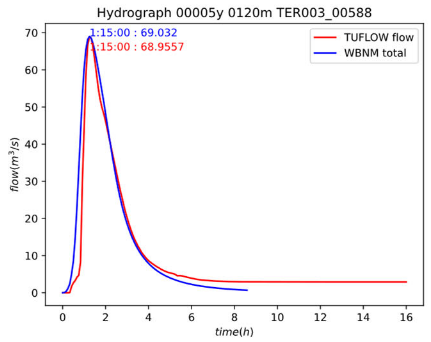



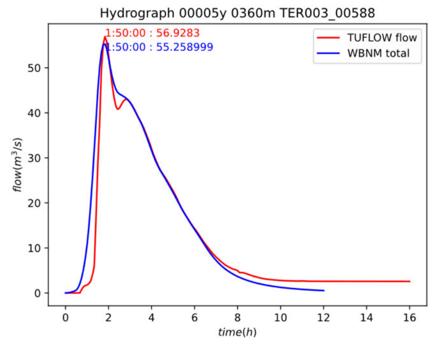



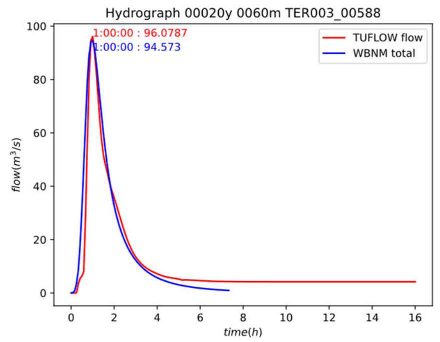



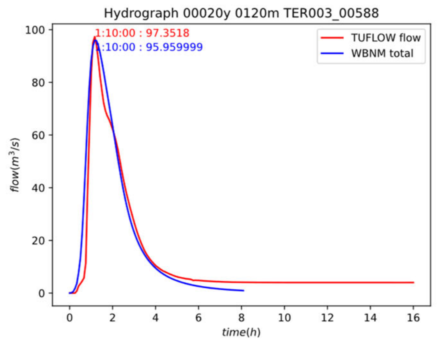

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.87 | -3.0 | -5.0 |
| 5-year 120-minute | 0.93 | -3.8 | 0.0 |
| 5-year 360-minute | 0.96 | -2.4 | -5.0 |
| 20-year 60-minute | 0.92 | -5.7 | 0.0 |
| 20-year 120-minute | 0.95 | -4.6 | 0.0 |
| 20-year 360-minute | 0.97 | -2.7 | -5.0 |
| 100-year 60-minute | 0.94 | -5.0 | 0.0 |
| 100-year 120-minute | 0.97 | -3.9 | 0.0 |
| 100-year 360-minute | 0.98 | -2.1 | -5.0 |
| 2000-year 60-minute | 0.97 | 1.6 | -5.0 |
| 2000-year 120-minute | 0.99 | 0.0 | -5.0 |
| 2000-year 360-minute | 0.99 | -0.2 | -5.0 |

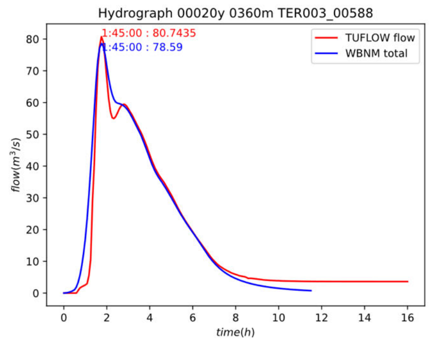


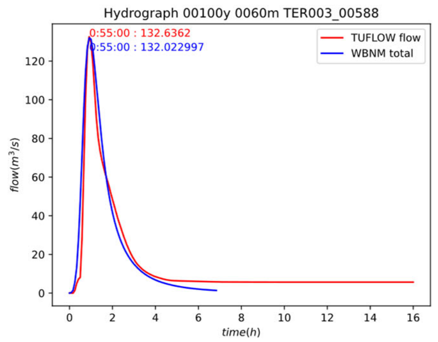



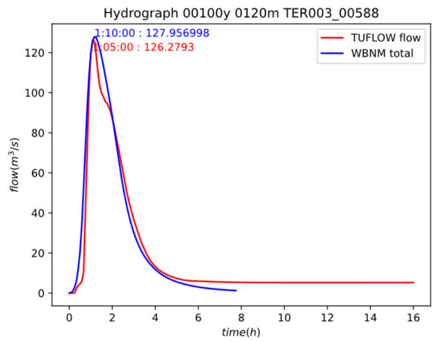



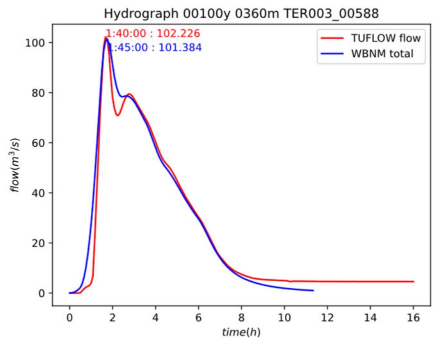



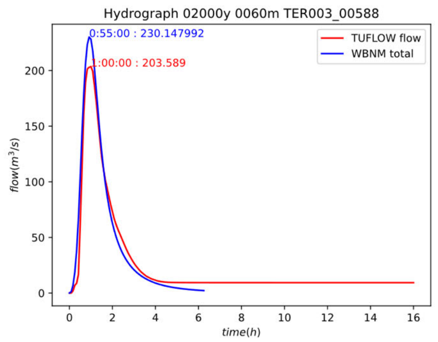



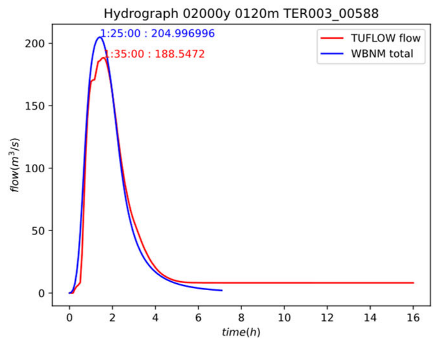



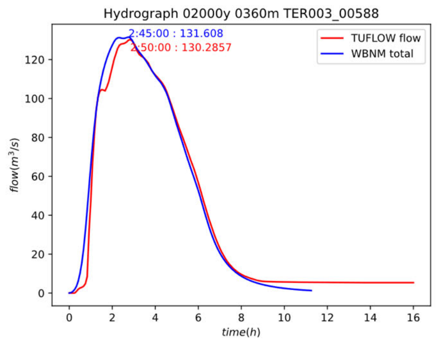



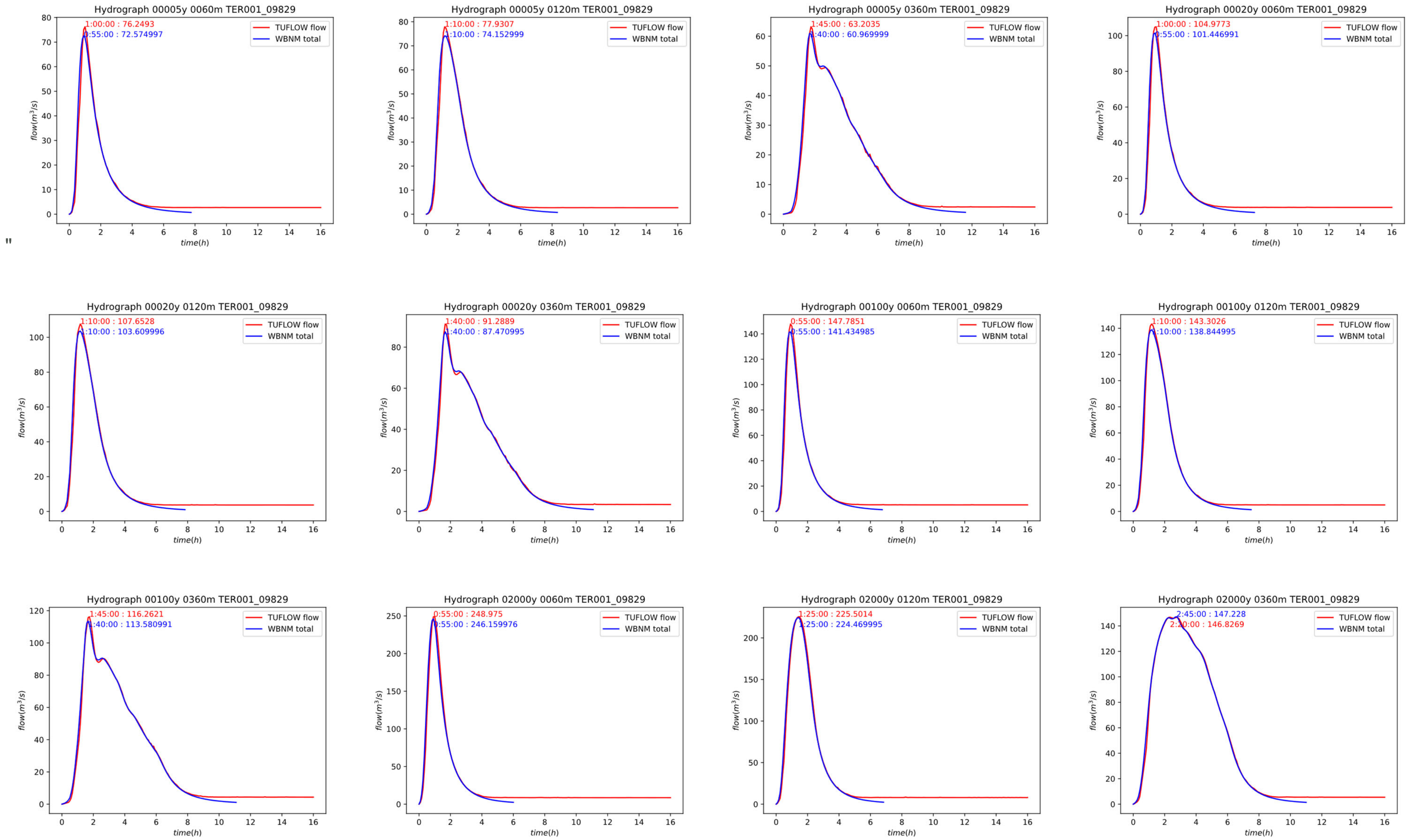



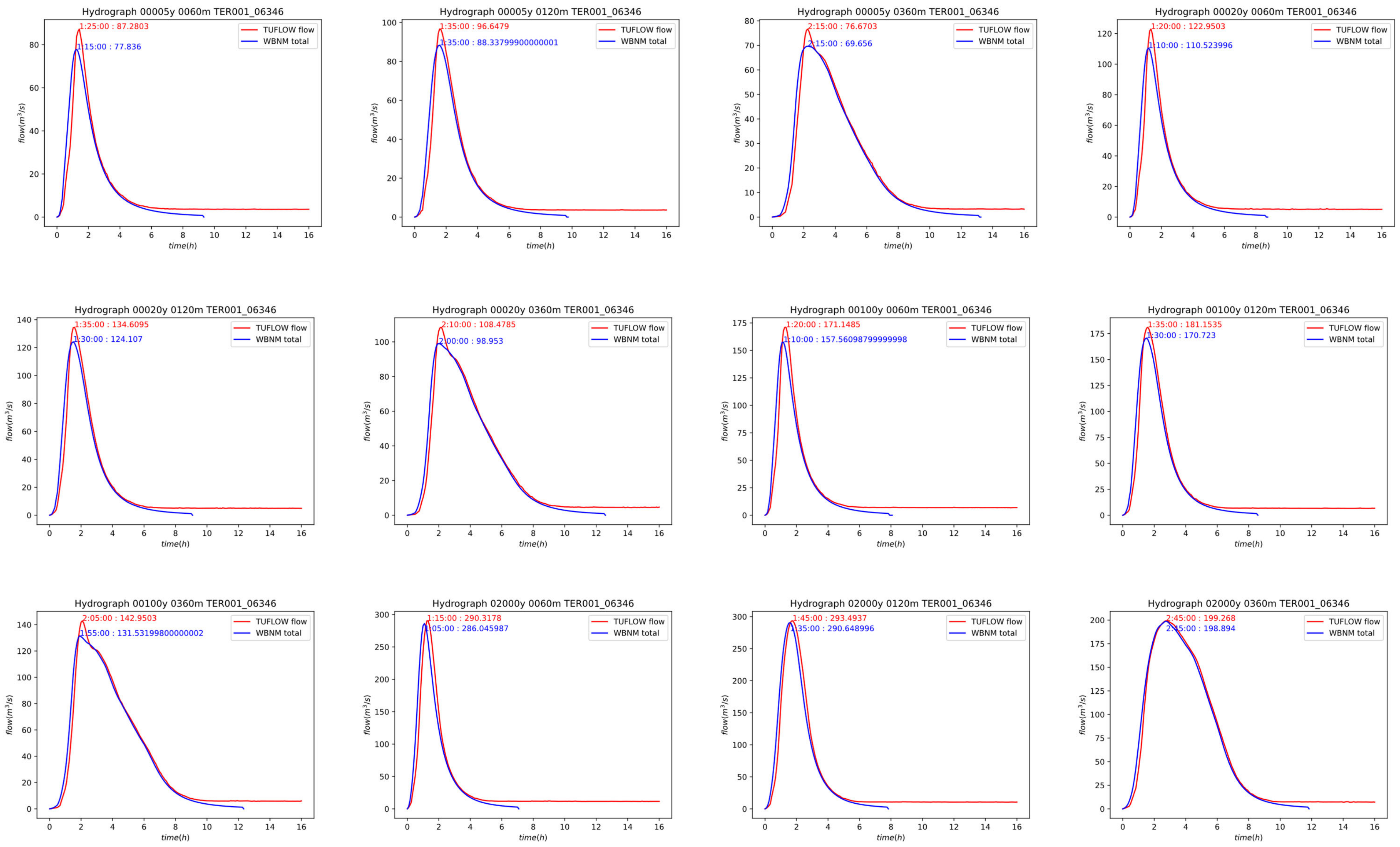




| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.87 | 1.3 | -5.0 |
| 5-year 120-minute | 0.91 | 0.1 | 0.0 |
| 5-year 360-minute | 0.93 | -2.9 | 0.0 |
| 20-year 60-minute | 0.91 | -1.6 | 0.0 |
| 20-year 120-minute | 0.94 | -1.4 | 0.0 |
| 20-year 360-minute | 0.96 | -2.7 | 0.0 |
| 100-year 60-minute | 0.94 | -0.5 | 0.0 |
| 100-year 120-minute | 0.96 | 1.3 | 5.0 |
| 100-year 360-minute | 0.97 | -0.8 | 5.0 |
| 2000-year 60-minute | 0.96 | 13.0 | -5.0 |
| 2000-year 120-minute | 0.98 | 8.7 | -10.0 |
| 2000-year 360-minute | 0.99 | 1.0 | -5.0 |




| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | -4.8 | -5.0 |
| 5-year 120-minute | 0.99 | -4.8 | 0.0 |
| 5-year 360-minute | 0.99 | -3.5 | -5.0 |
| 20-year 60-minute | 0.99 | -3.4 | -5.0 |
| 20-year 120-minute | 0.99 | -3.8 | 0.0 |
| 20-year 360-minute | 1.00 | -4.2 | 0.0 |
| 100-year 60-minute | 0.99 | -4.3 | 0.0 |
| 100-year 120-minute | 0.99 | -3.1 | 0.0 |
| 100-year 360-minute | 1.00 | -2.3 | -5.0 |
| 2000-year 60-minute | 0.99 | -1.1 | 0.0 |
| 2000-year 120-minute | 1.00 | -0.5 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.3 | 25.0 |

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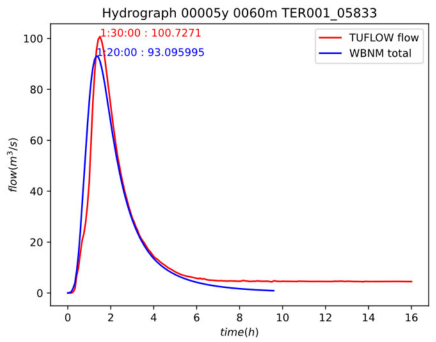
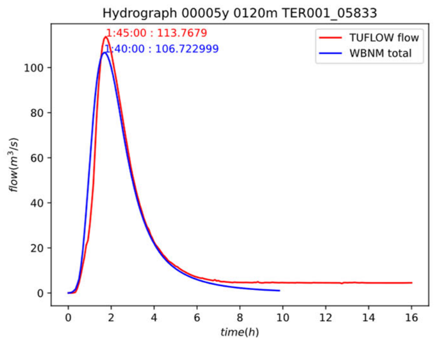
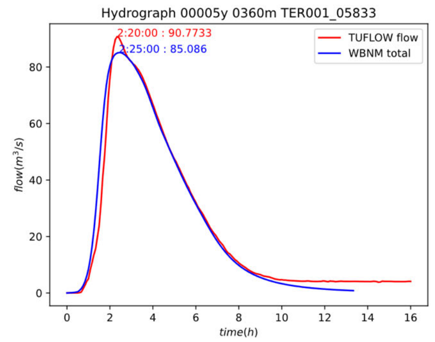
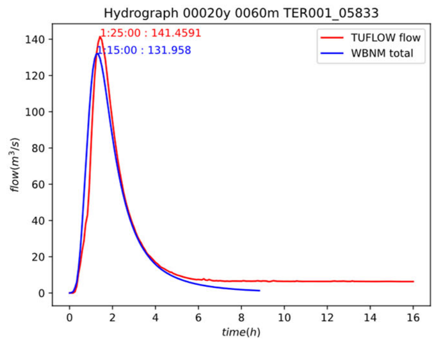
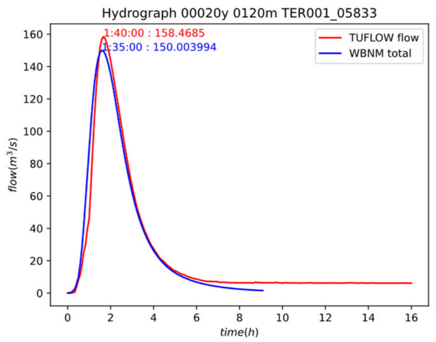
| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.93 | -10.8 | -10.0 |
| 5-year 120-minute | 0.96 | -8.6 | 0.0 |
| 5-year 360-minute | 0.98 | -9.1 | 0.0 |
| 20-year 60-minute | 0.94 | -10.1 | -10.0 |
| 20-year 120-minute | 0.96 | -7.8 | -5.0 |
| 20-year 360-minute | 0.98 | -8.8 | -10.0 |
| 100-year 60-minute | 0.94 | -7.9 | -10.0 |
| 100-year 120-minute | 0.97 | -5.8 | -5.0 |
| 100-year 360-minute | 0.98 | -8.0 | -10.0 |
| 2000-year 60-minute | 0.93 | -1.5 | -10.0 |
| 2000-year 120-minute | 0.97 | -1.0 | -10.0 |
| 2000-year 360-minute | 0.99 | -0.2 | 0.0 |

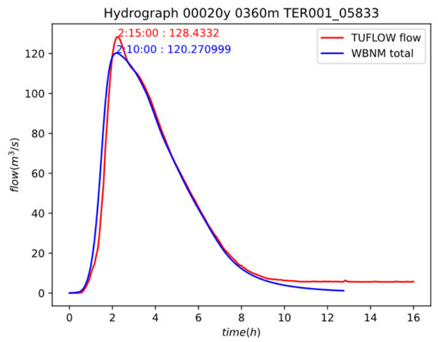


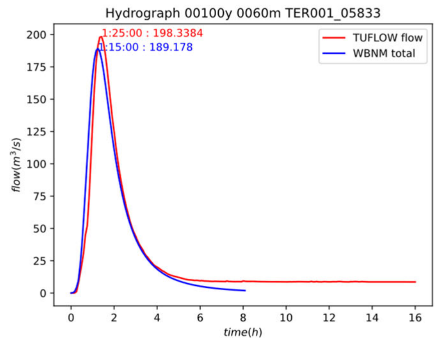



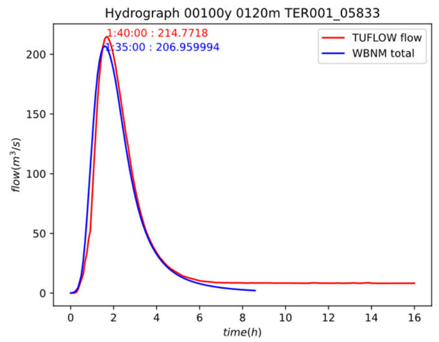



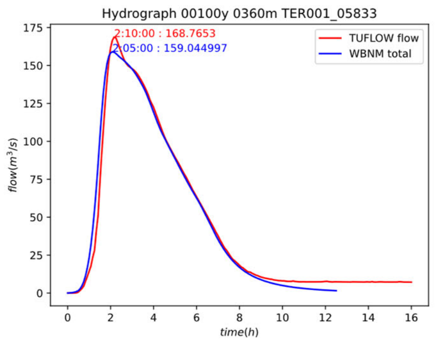



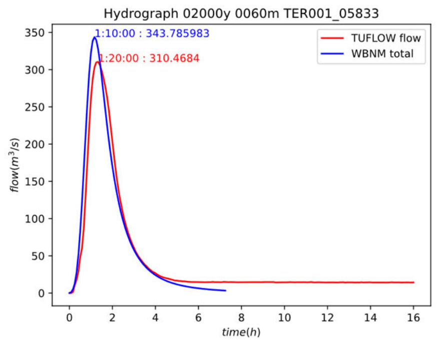



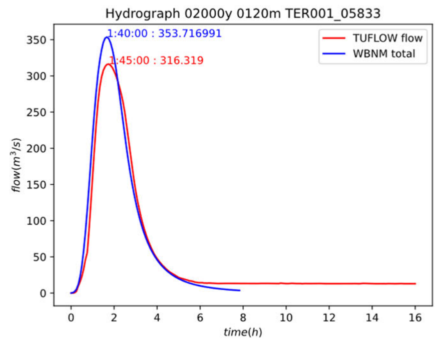



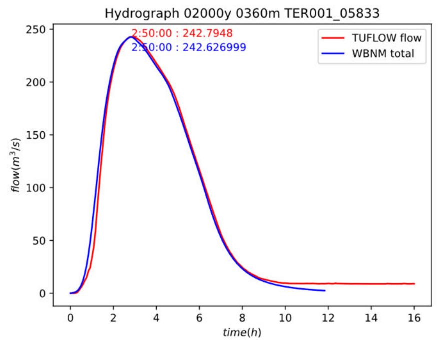



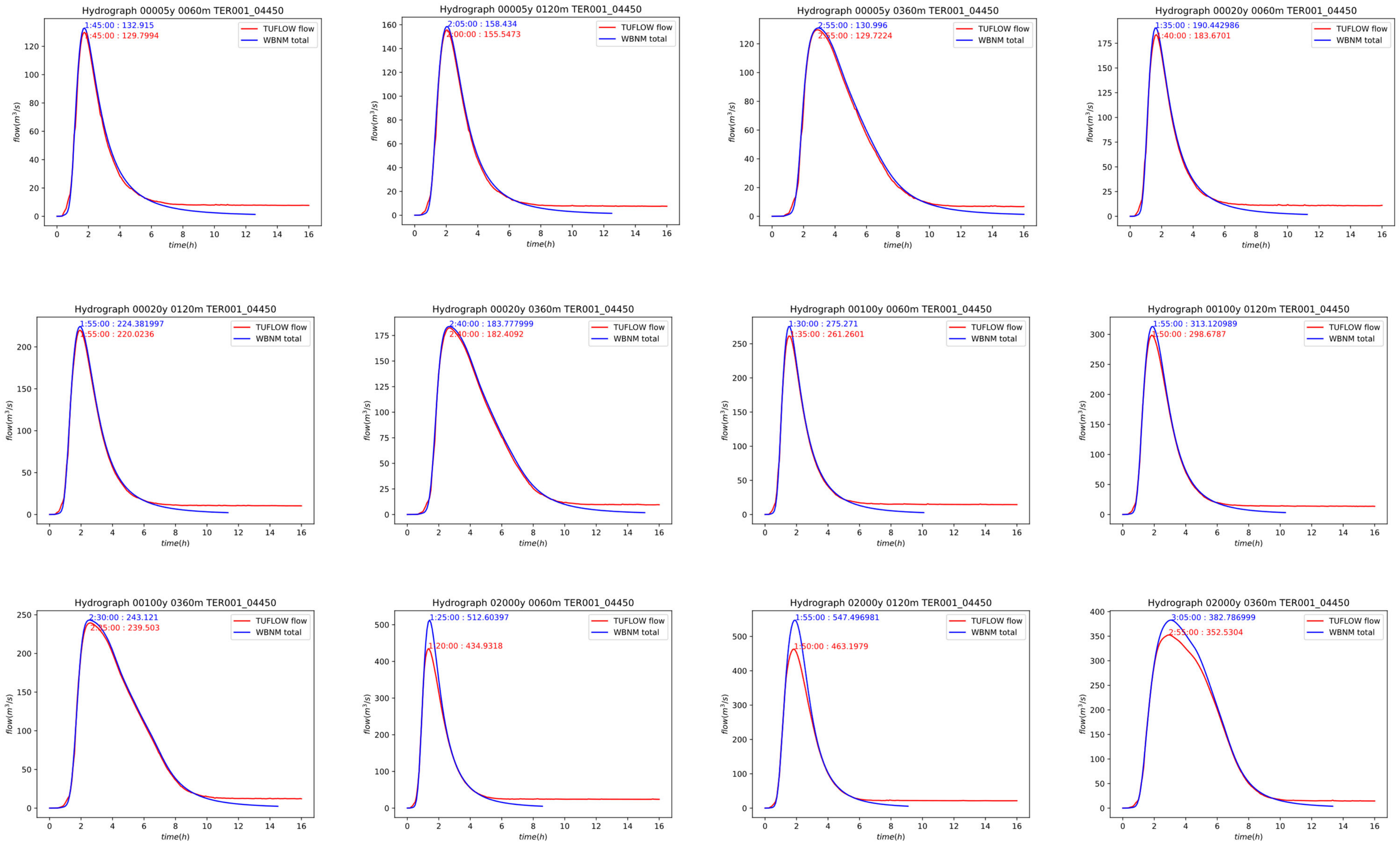



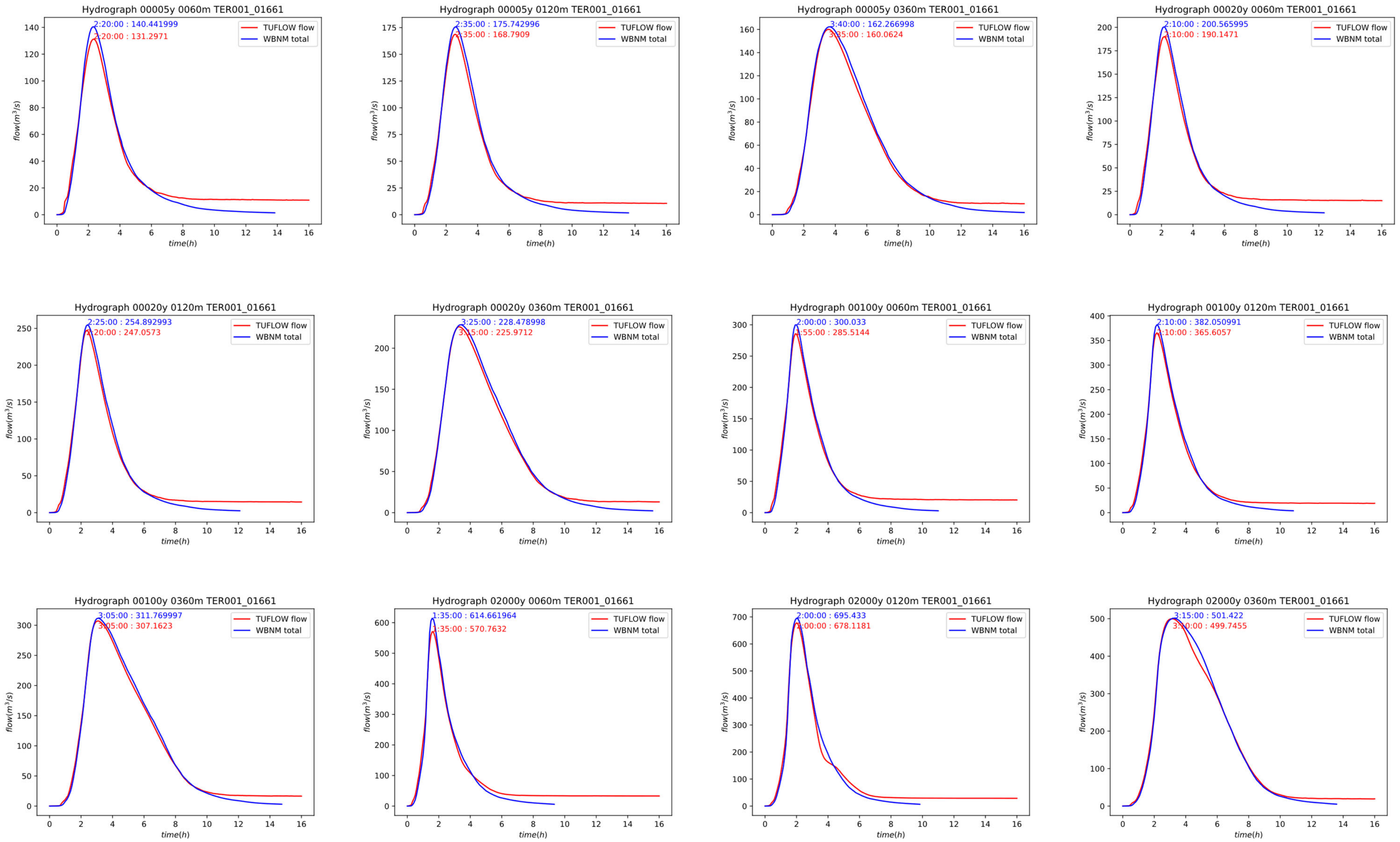



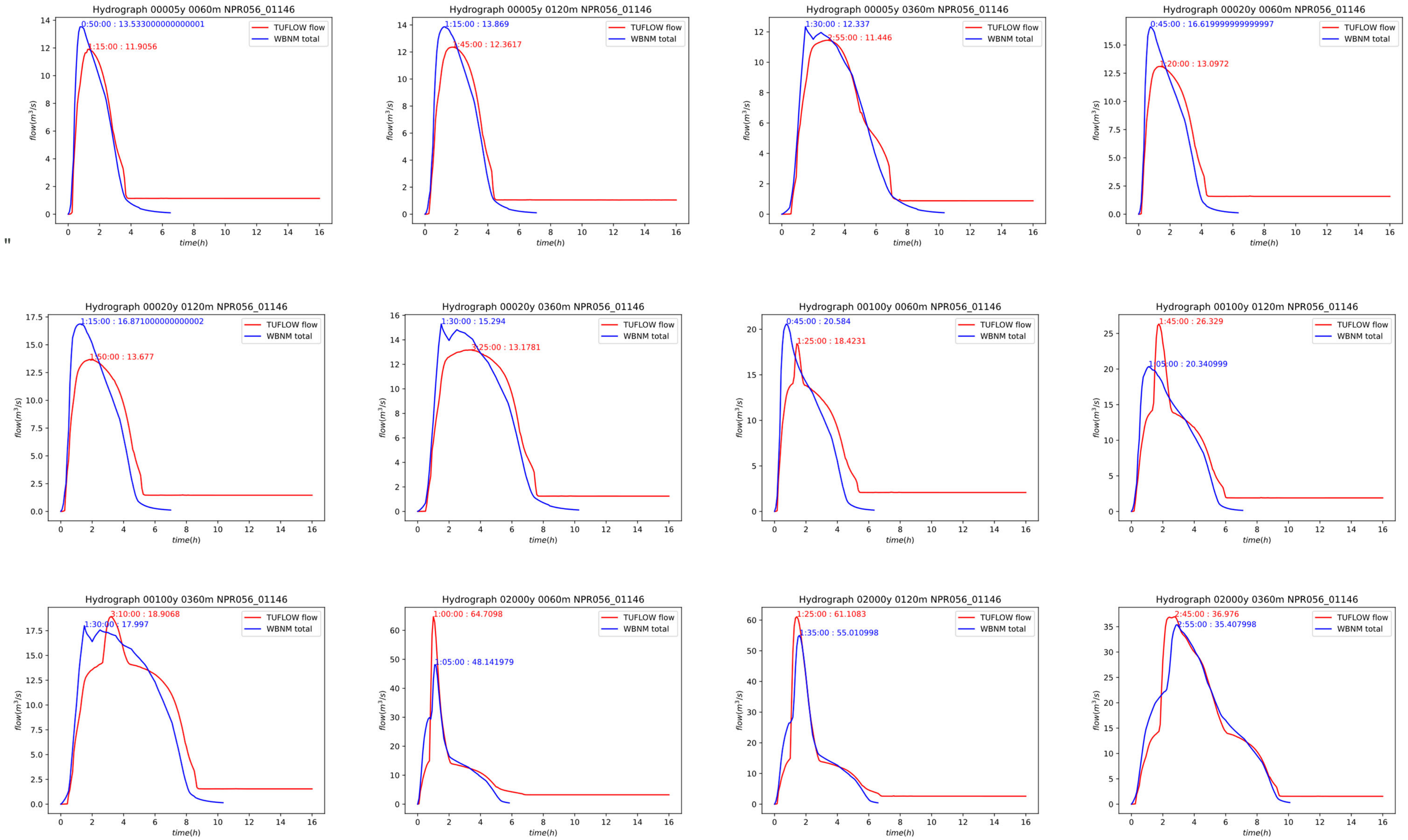

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | -7.6 | -10.0 |
| 5-year 120-minute | 0.96 | -6.2 | -5.0 |
| 5-year 360-minute | 0.98 | -6.3 | 5.0 |
| 20-year 60-minute | 0.95 | -6.7 | -10.0 |
| 20-year 120-minute | 0.97 | -5.3 | -5.0 |
| 20-year 360-minute | 0.98 | -6.4 | -5.0 |
| 100-year 60-minute | 0.95 | -4.6 | -10.0 |
| 100-year 120-minute | 0.97 | -3.6 | -5.0 |
| 100-year 360-minute | 0.99 | -5.8 | -5.0 |
| 2000-year 60-minute | 0.95 | 10.7 | -10.0 |
| 2000-year 120-minute | 0.97 | 11.8 | -5.0 |
| 2000-year 360-minute | 0.99 | -0.1 | 0.0 |



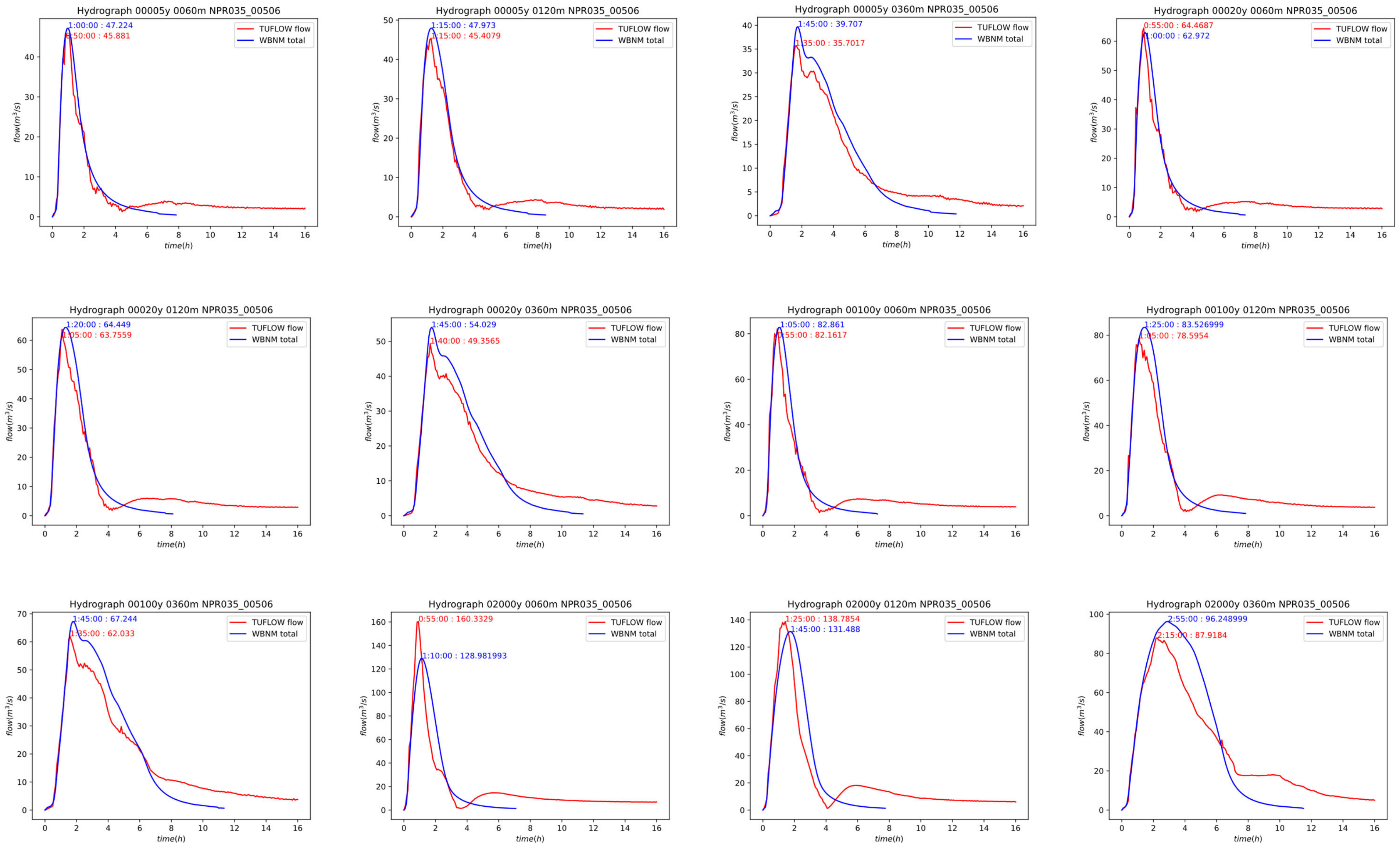

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.99 | 2.4 | 0.0 |
| 5-year 120-minute | 0.99 | 1.9 | 5.0 |
| 5-year 360-minute | 0.99 | 1.0 | 0.0 |
| 20-year 60-minute | 0.99 | 3.7 | -5.0 |
| 20-year 120-minute | 0.99 | 2.0 | 0.0 |
| 20-year 360-minute | 1.00 | 0.8 | 0.0 |
| 100-year 60-minute | 0.99 | 5.4 | -5.0 |
| 100-year 120-minute | 0.99 | 4.8 | 5.0 |
| 100-year 360-minute | 1.00 | 1.5 | -5.0 |
| 2000-year 60-minute | 0.97 | 17.9 | 5.0 |
| 2000-year 120-minute | 0.97 | 18.2 | 5.0 |
| 2000-year 360-minute | 0.99 | 8.6 | 10.0 |



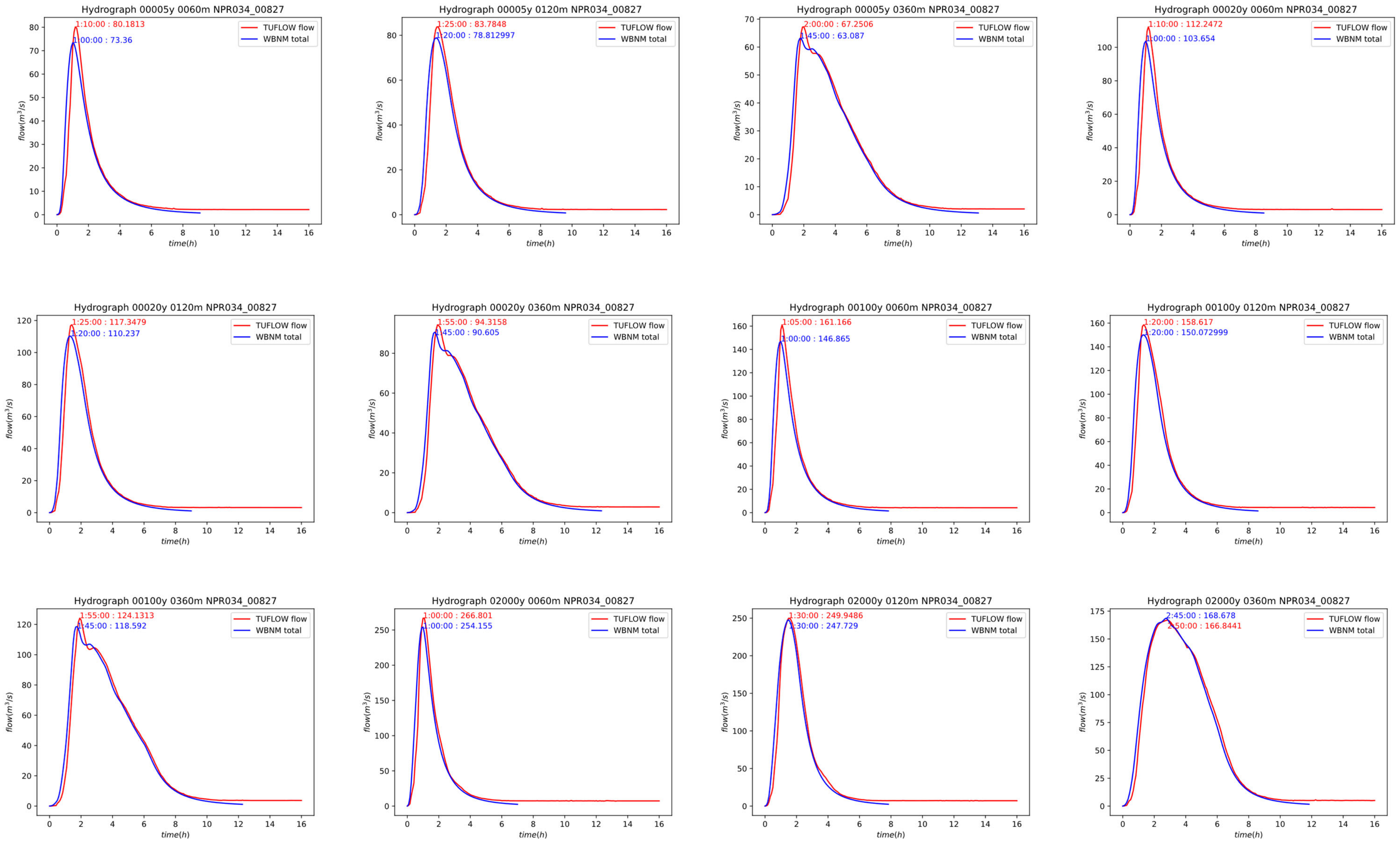

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.97 | 7.0 | 0.0 |
| 5-year 120-minute | 0.98 | 4.1 | 0.0 |
| 5-year 360-minute | 0.99 | 1.4 | 5.0 |
| 20-year 60-minute | 0.98 | 5.5 | 0.0 |
| 20-year 120-minute | 0.99 | 3.2 | 5.0 |
| 20-year 360-minute | 0.99 | 1.1 | 10.0 |
| 100-year 60-minute | 0.98 | 5.1 | 5.0 |
| 100-year 120-minute | 0.99 | 4.5 | 0.0 |
| 100-year 360-minute | 1.00 | 1.5 | 0.0 |
| 2000-year 60-minute | 0.99 | 7.7 | 0.0 |
| 2000-year 120-minute | 0.99 | 2.6 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.3 | 5.0 |



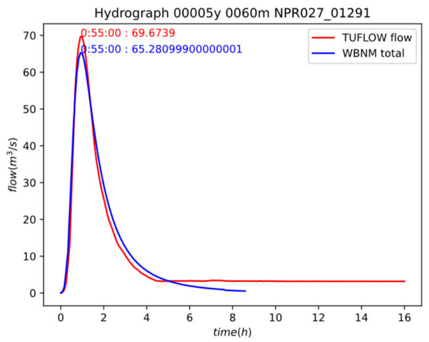

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.92 | 13.7 | -25.0 |
| 5-year 120-minute | 0.93 | 12.2 | -30.0 |
| 5-year 360-minute | 0.96 | 7.8 | -85.0 |
| 20-year 60-minute | 0.86 | 26.9 | -35.0 |
| 20-year 120-minute | 0.86 | 23.4 | -35.0 |
| 20-year 360-minute | 0.94 | 16.1 | -115.0 |
| 100-year 60-minute | 0.78 | 11.7 | -40.0 |
| 100-year 120-minute | 0.86 | -22.7 | -40.0 |
| 100-year 360-minute | 0.90 | -4.8 | -100.0 |
| 2000-year 60-minute | 0.86 | -25.6 | 5.0 |
| 2000-year 120-minute | 0.92 | -10.0 | 10.0 |
| 2000-year 360-minute | 0.95 | -4.2 | 10.0 |

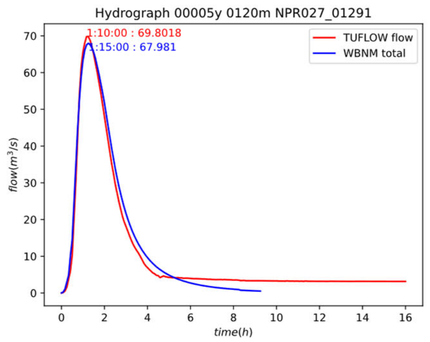


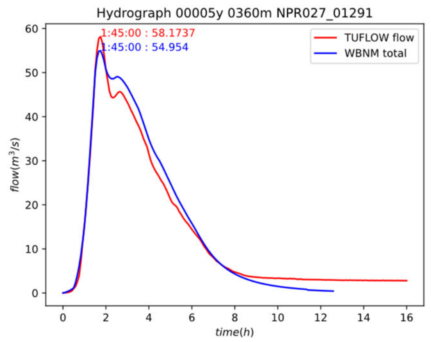

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | 2.9 | 10.0 |
| 5-year 120-minute | 0.96 | 5.6 | 0.0 |
| 5-year 360-minute | 0.94 | 11.2 | 10.0 |
| 20-year 60-minute | 0.94 | -2.3 | 5.0 |
| 20-year 120-minute | 0.94 | 1.1 | 15.0 |
| 20-year 360-minute | 0.93 | 9.5 | 5.0 |
| 100-year 60-minute | 0.92 | 0.9 | 10.0 |
| 100-year 120-minute | 0.92 | 6.3 | 20.0 |
| 100-year 360-minute | 0.90 | 8.4 | 10.0 |
| 2000-year 60-minute | 0.82 | -19.6 | 15.0 |
| 2000-year 120-minute | 0.83 | -5.3 | 20.0 |
| 2000-year 360-minute | 0.79 | 9.5 | 40.0 |

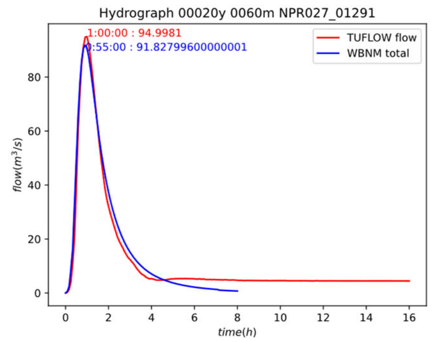


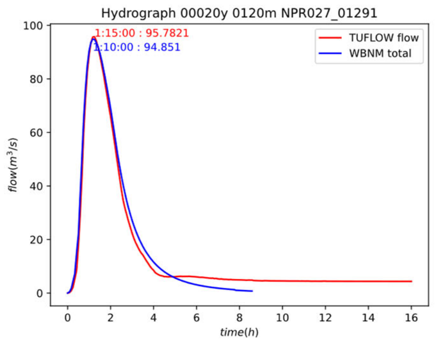

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.92 | -8.5 | -10.0 |
| 5-year 120-minute | 0.96 | -5.9 | -5.0 |
| 5-year 360-minute | 0.98 | -6.2 | -15.0 |
| 20-year 60-minute | 0.92 | -7.7 | -10.0 |
| 20-year 120-minute | 0.95 | -6.1 | -5.0 |
| 20-year 360-minute | 0.98 | -3.9 | -10.0 |
| 100-year 60-minute | 0.92 | -8.9 | -5.0 |
| 100-year 120-minute | 0.96 | -5.4 | 0.0 |
| 100-year 360-minute | 0.98 | -4.5 | -10.0 |
| 2000-year 60-minute | 0.94 | -4.7 | 0.0 |
| 2000-year 120-minute | 0.97 | -0.9 | 0.0 |
| 2000-year 360-minute | 0.99 | 1.1 | -5.0 |

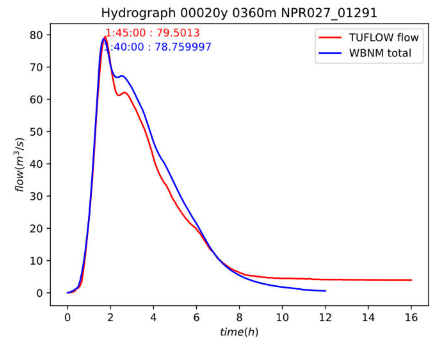


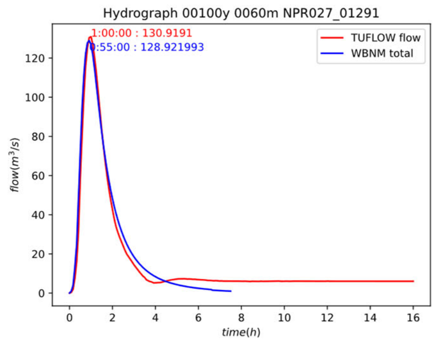



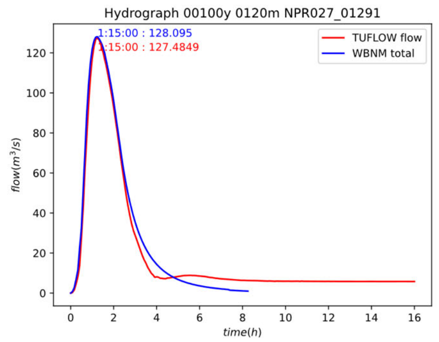



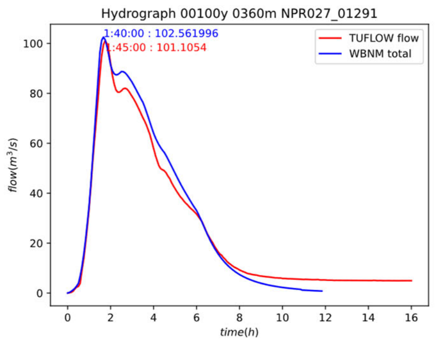



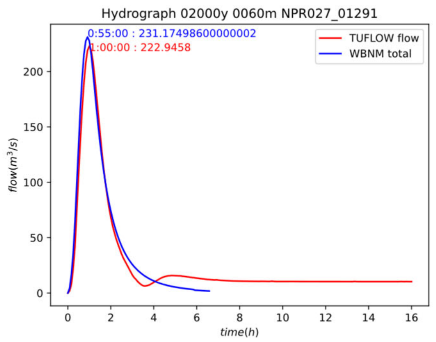



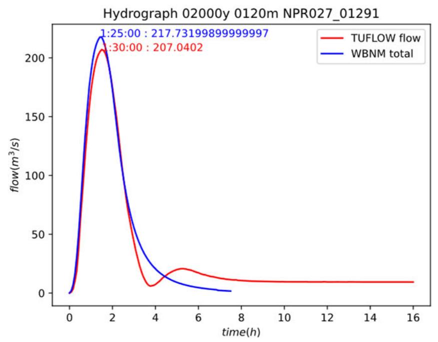



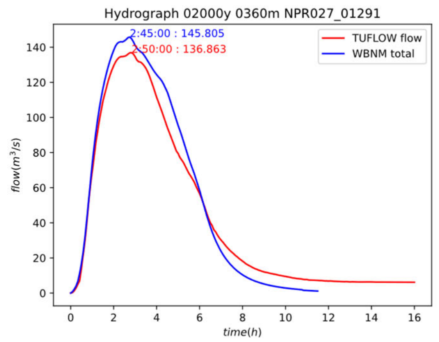



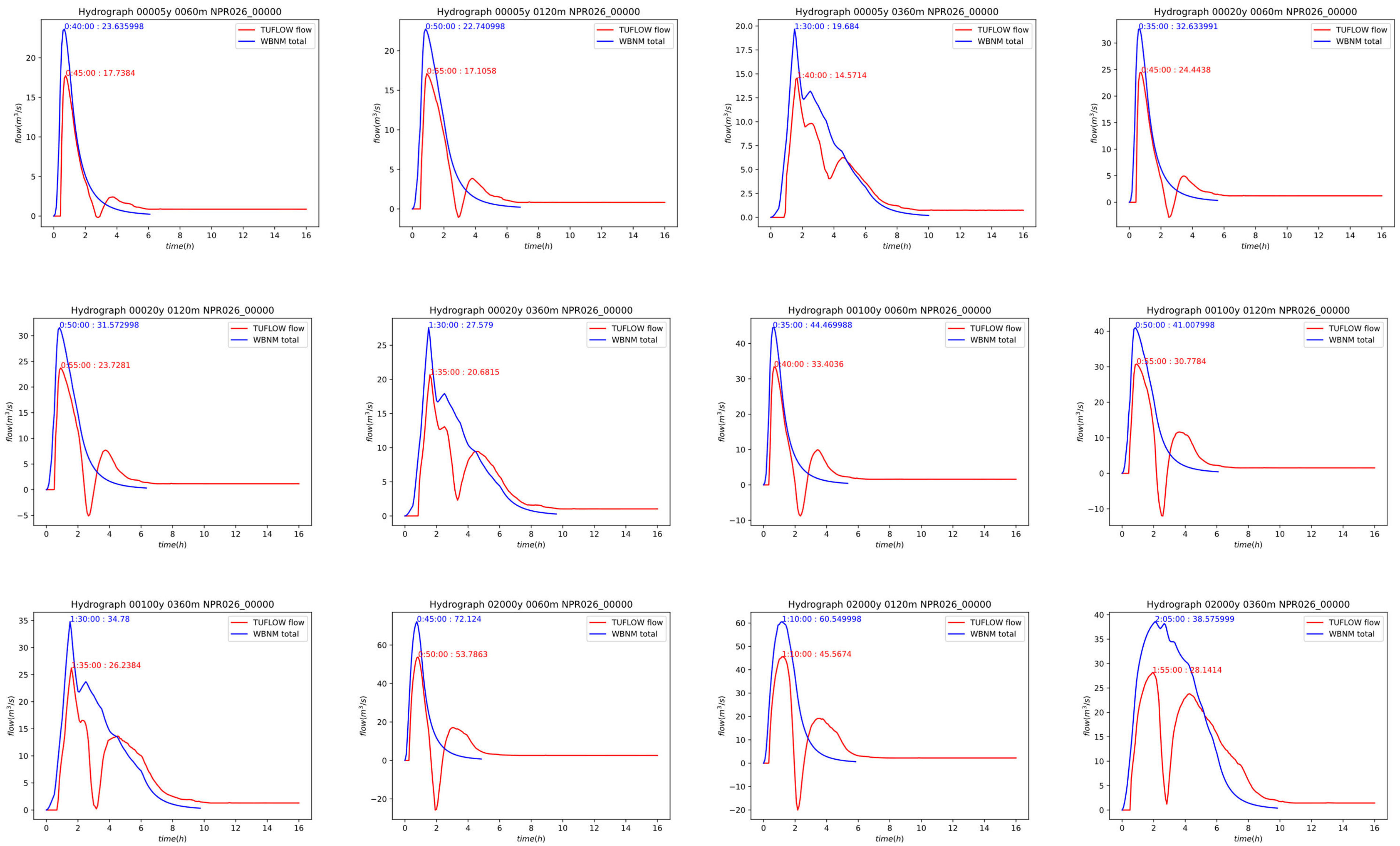



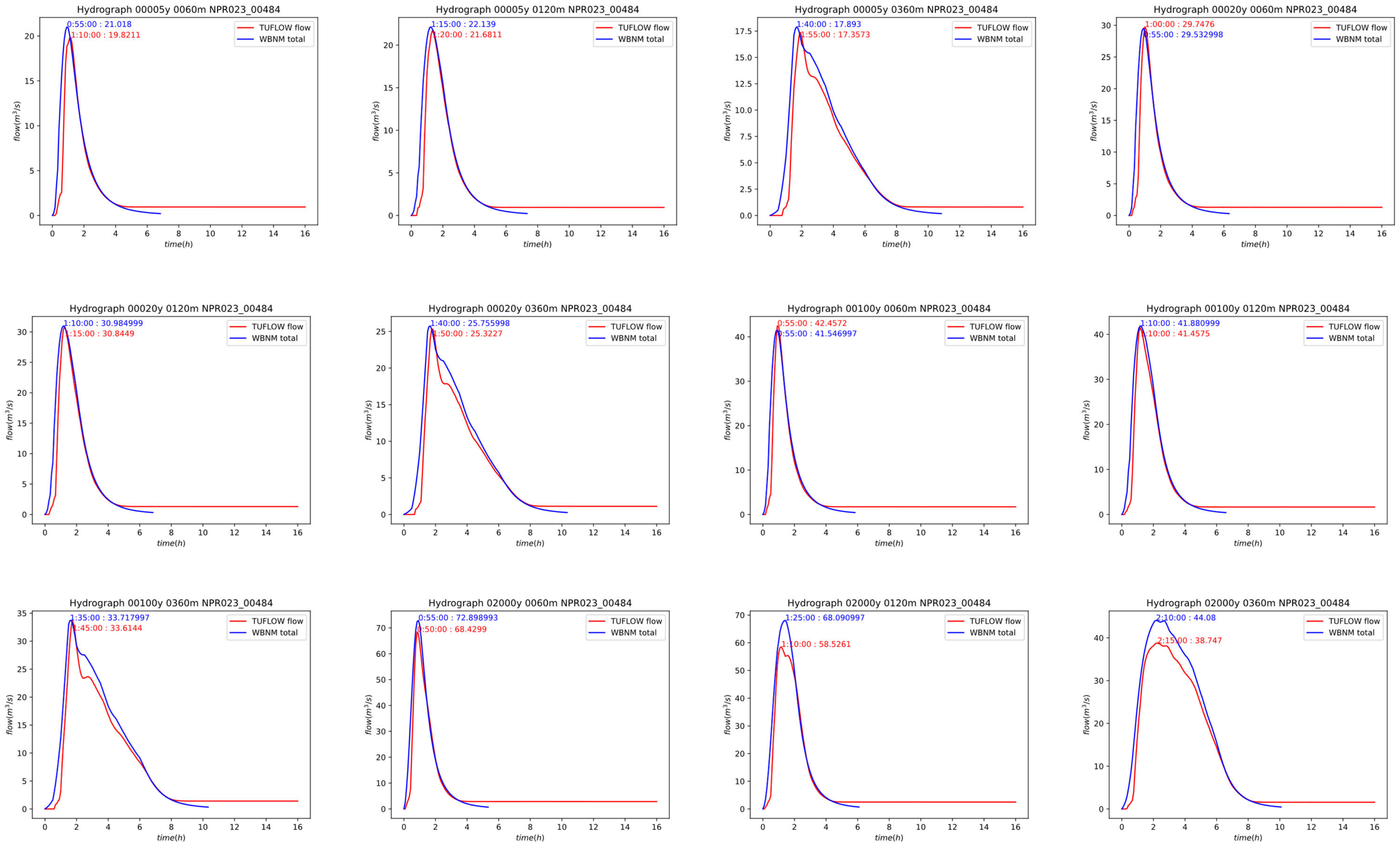



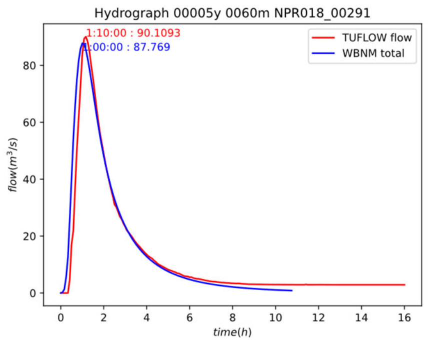

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | -6.3 | 0.0 |
| 5-year 120-minute | 0.99 | -2.6 | 5.0 |
| 5-year 360-minute | 0.98 | -5.5 | 0.0 |
| 20-year 60-minute | 0.98 | -3.3 | -5.0 |
| 20-year 120-minute | 0.99 | -1.0 | -5.0 |
| 20-year 360-minute | 0.98 | -0.9 | -5.0 |
| 100-year 60-minute | 0.98 | -1.5 | -5.0 |
| 100-year 120-minute | 0.99 | 0.5 | 0.0 |
| 100-year 360-minute | 0.98 | 1.4 | -5.0 |
| 2000-year 60-minute | 0.98 | 3.7 | -5.0 |
| 2000-year 120-minute | 0.98 | 5.2 | -5.0 |
| 2000-year 360-minute | 0.98 | 6.5 | -5.0 |

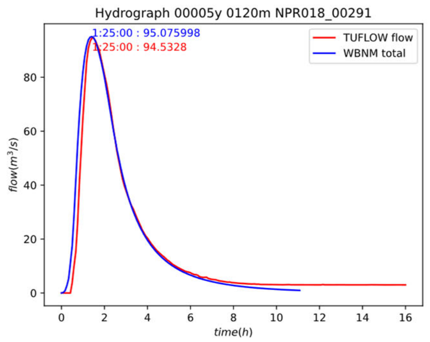


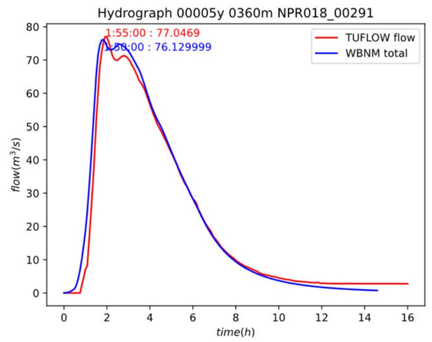

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.62 | 33.2 | -5.0 |
| 5-year 120-minute | 0.68 | 32.9 | -5.0 |
| 5-year 360-minute | 0.65 | 35.1 | -10.0 |
| 20-year 60-minute | 0.58 | 33.5 | -10.0 |
| 20-year 120-minute | 0.56 | 33.1 | -5.0 |
| 20-year 360-minute | 0.51 | 33.4 | -5.0 |
| 100-year 60-minute | 0.55 | 33.1 | -5.0 |
| 100-year 120-minute | 0.39 | 33.2 | -5.0 |
| 100-year 360-minute | 0.32 | 32.6 | -5.0 |
| 2000-year 60-minute | 0.41 | 34.1 | -5.0 |
| 2000-year 120-minute | 0.10 | 32.9 | 0.0 |
| 2000-year 360-minute | 0.09 | 37.1 | 10.0 |

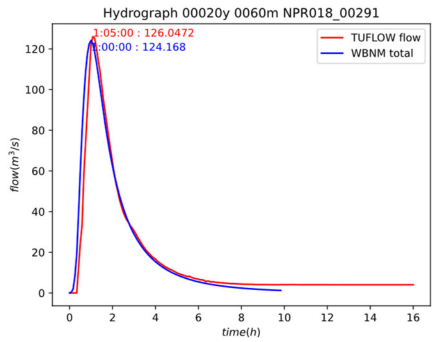


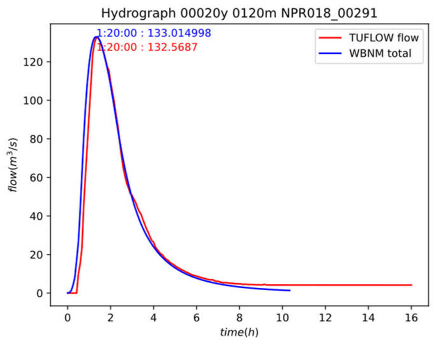

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.82 | 6.0 | -15.0 |
| 5-year 120-minute | 0.89 | 2.1 | -5.0 |
| 5-year 360-minute | 0.91 | 3.1 | -15.0 |
| 20-year 60-minute | 0.86 | -0.7 | -5.0 |
| 20-year 120-minute | 0.91 | 0.5 | -5.0 |
| 20-year 360-minute | 0.93 | 1.7 | -10.0 |
| 100-year 60-minute | 0.89 | -2.1 | 0.0 |
| 100-year 120-minute | 0.93 | 1.0 | 0.0 |
| 100-year 360-minute | 0.94 | 0.3 | -10.0 |
| 2000-year 60-minute | 0.92 | 6.5 | 5.0 |
| 2000-year 120-minute | 0.94 | 16.3 | 15.0 |
| 2000-year 360-minute | 0.96 | 13.8 | -5.0 |

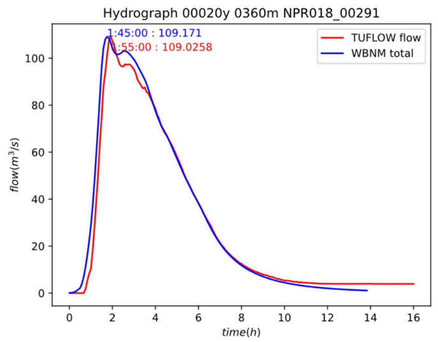


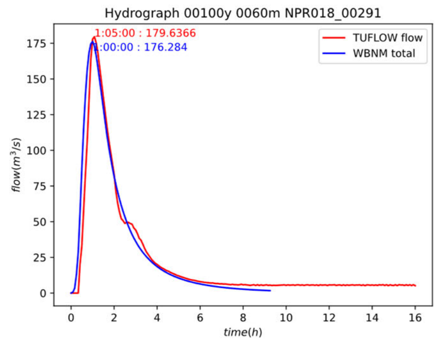



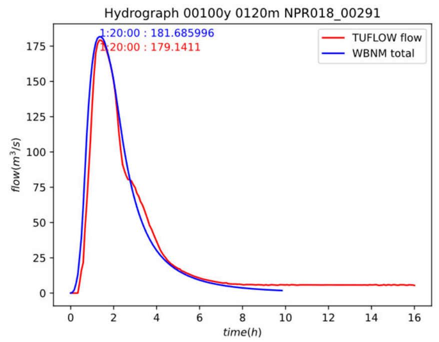



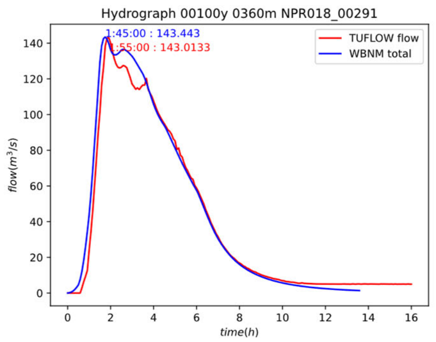



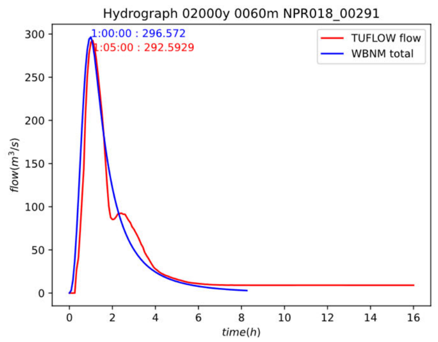



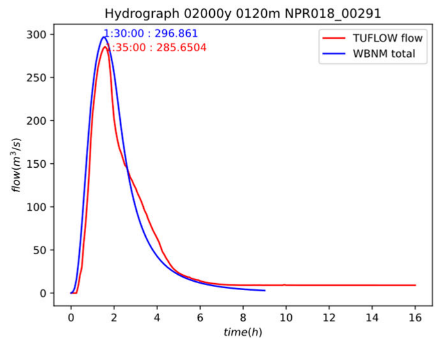



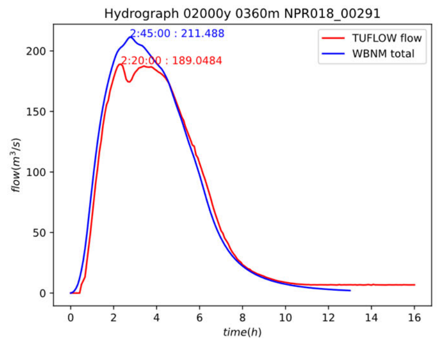



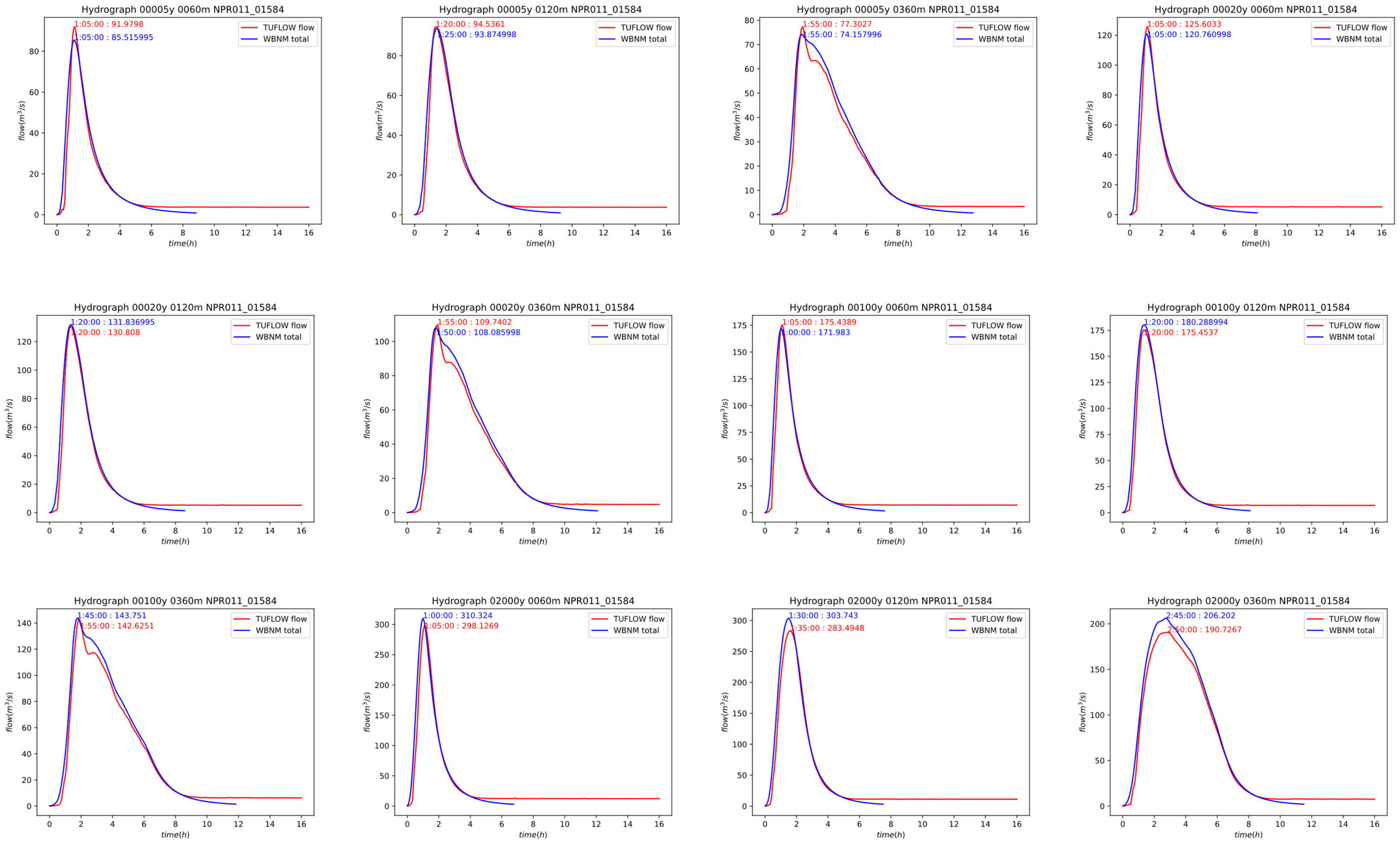



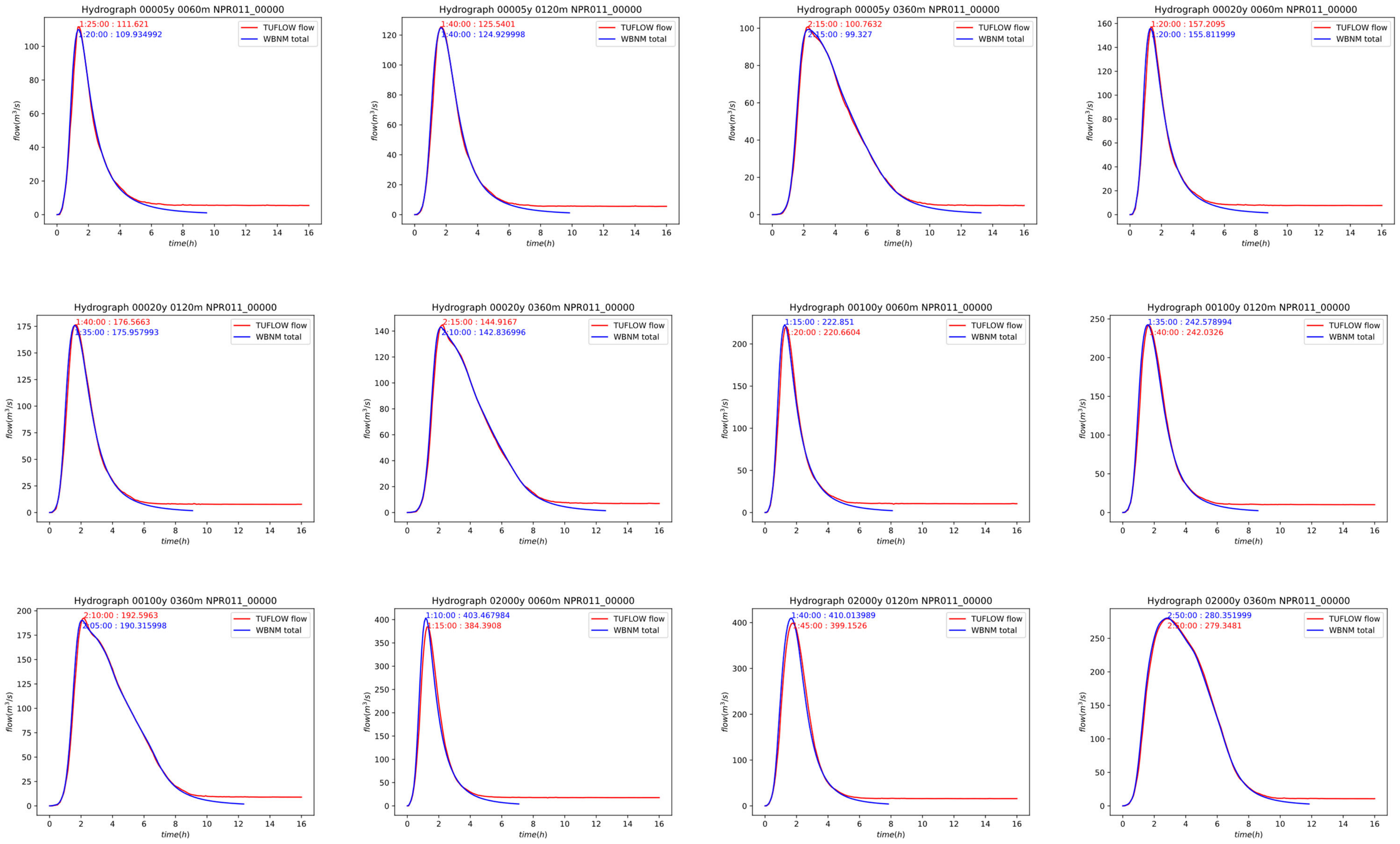



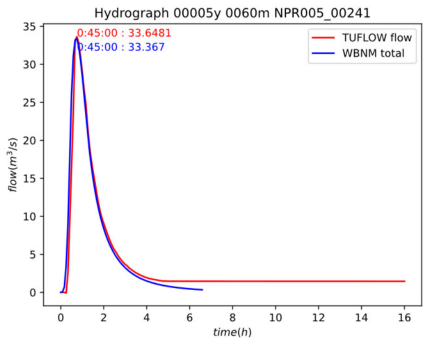

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | -2.6 | -10.0 |
| 5-year 120-minute | 0.96 | 0.6 | 0.0 |
| 5-year 360-minute | 0.98 | -1.2 | -5.0 |
| 20-year 60-minute | 0.94 | -1.5 | -5.0 |
| 20-year 120-minute | 0.96 | 0.3 | 0.0 |
| 20-year 360-minute | 0.98 | 0.1 | -10.0 |
| 100-year 60-minute | 0.94 | -1.9 | -5.0 |
| 100-year 120-minute | 0.96 | 1.4 | 0.0 |
| 100-year 360-minute | 0.98 | 0.3 | -10.0 |
| 2000-year 60-minute | 0.93 | 1.4 | -5.0 |
| 2000-year 120-minute | 0.95 | 3.9 | -5.0 |
| 2000-year 360-minute | 0.98 | 11.9 | 25.0 |

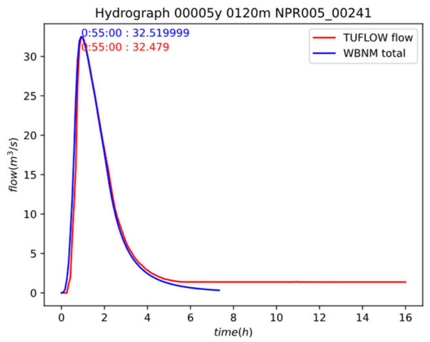


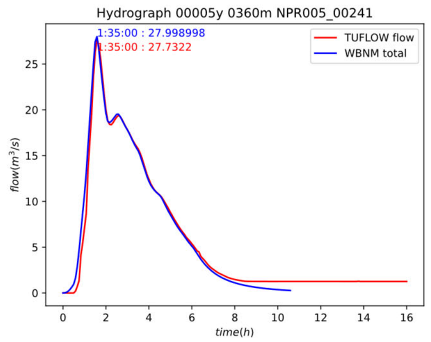

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | -7.0 | 0.0 |
| 5-year 120-minute | 0.97 | -0.7 | 5.0 |
| 5-year 360-minute | 0.98 | -4.1 | 0.0 |
| 20-year 60-minute | 0.96 | -3.9 | 0.0 |
| 20-year 120-minute | 0.98 | 0.8 | 0.0 |
| 20-year 360-minute | 0.98 | -1.5 | -5.0 |
| 100-year 60-minute | 0.96 | -2.0 | -5.0 |
| 100-year 120-minute | 0.98 | 2.8 | 0.0 |
| 100-year 360-minute | 0.98 | 0.8 | -10.0 |
| 2000-year 60-minute | 0.96 | 4.1 | -5.0 |
| 2000-year 120-minute | 0.98 | 7.1 | -5.0 |
| 2000-year 360-minute | 0.99 | 8.1 | -5.0 |

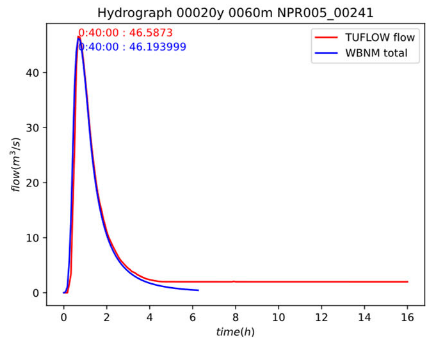


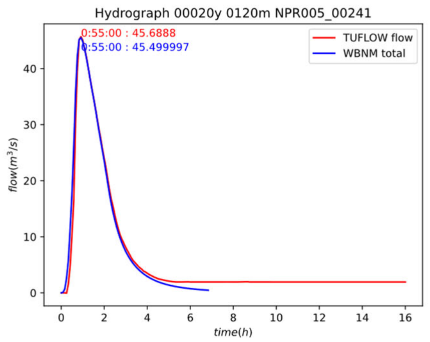

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.99 | -1.5 | -5.0 |
| 5-year 120-minute | 0.99 | -0.5 | 0.0 |
| 5-year 360-minute | 1.00 | -1.4 | 0.0 |
| 20-year 60-minute | 0.99 | -0.9 | 0.0 |
| 20-year 120-minute | 0.99 | -0.3 | -5.0 |
| 20-year 360-minute | 1.00 | -1.4 | -5.0 |
| 100-year 60-minute | 0.98 | 1.0 | -5.0 |
| 100-year 120-minute | 0.99 | 0.2 | -5.0 |
| 100-year 360-minute | 1.00 | -1.2 | -5.0 |
| 2000-year 60-minute | 0.98 | 5.0 | -5.0 |
| 2000-year 120-minute | 0.99 | 2.7 | -5.0 |
| 2000-year 360-minute | 1.00 | 0.4 | 0.0 |

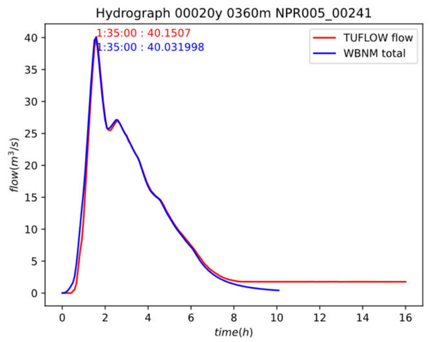


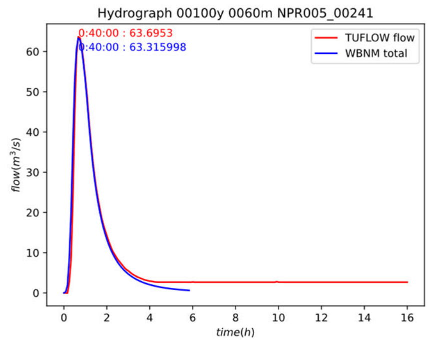



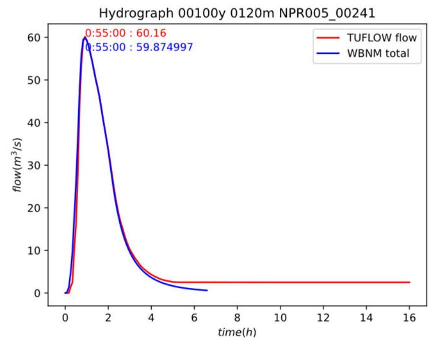



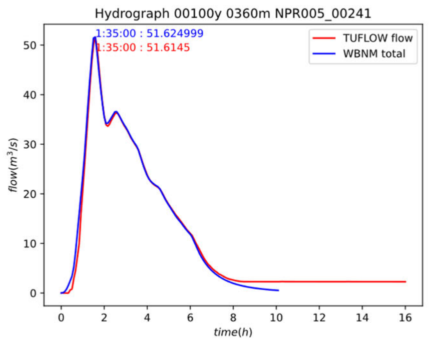



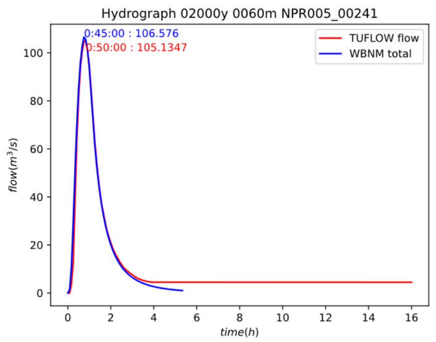



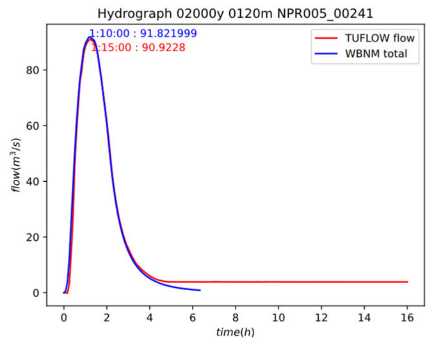



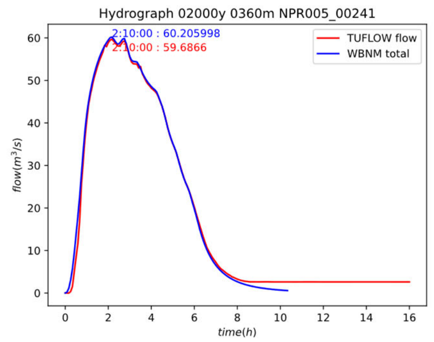



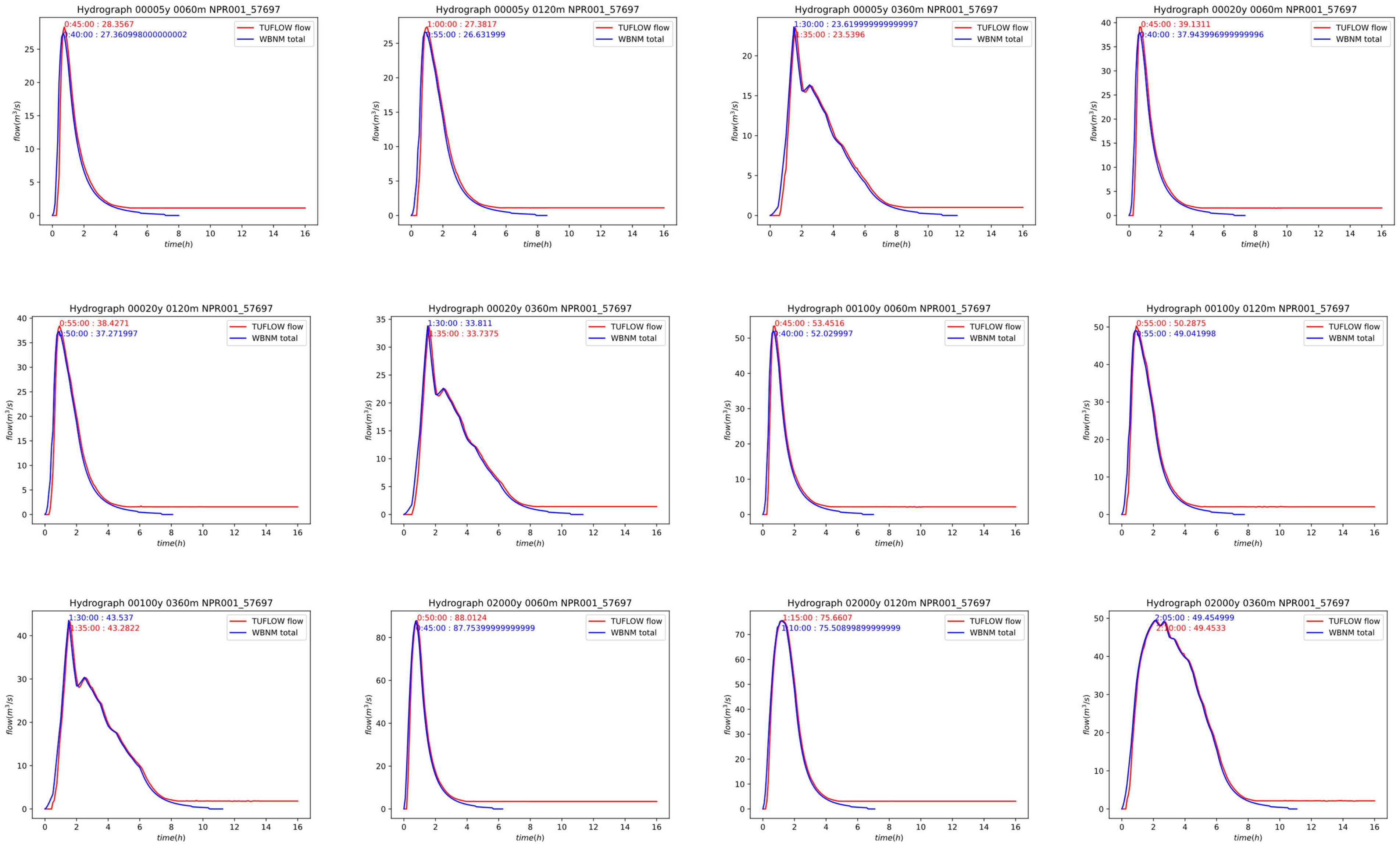




| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | -0.8 | 0.0 |
| 5-year 120-minute | 0.98 | 0.1 | 0.0 |
| 5-year 360-minute | 0.99 | 1.0 | 0.0 |
| 20-year 60-minute | 0.97 | -0.8 | 0.0 |
| 20-year 120-minute | 0.99 | -0.4 | 0.0 |
| 20-year 360-minute | 0.99 | -0.3 | 0.0 |
| 100-year 60-minute | 0.98 | -0.6 | 0.0 |
| 100-year 120-minute | 0.99 | -0.5 | 0.0 |
| 100-year 360-minute | 0.99 | 0.0 | 0.0 |
| 2000-year 60-minute | 0.99 | 1.4 | -5.0 |
| 2000-year 120-minute | 0.99 | 1.0 | -5.0 |
| 2000-year 360-minute | 1.00 | 0.9 | 0.0 |

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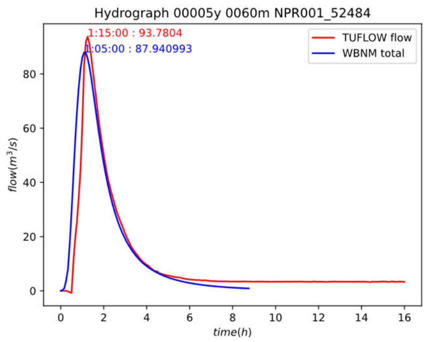
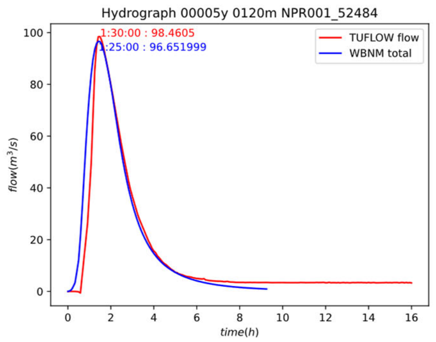
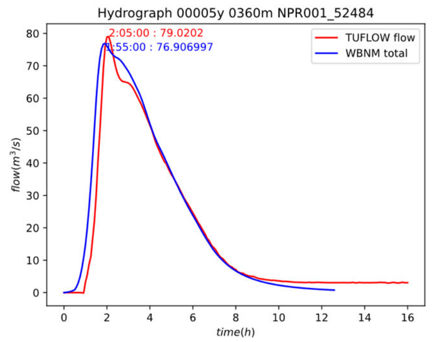
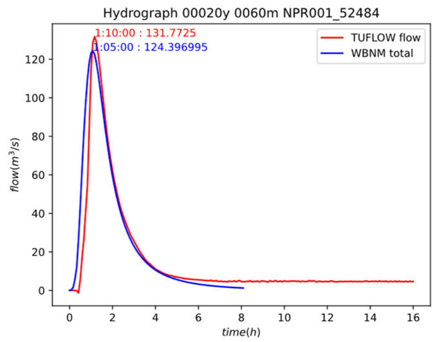
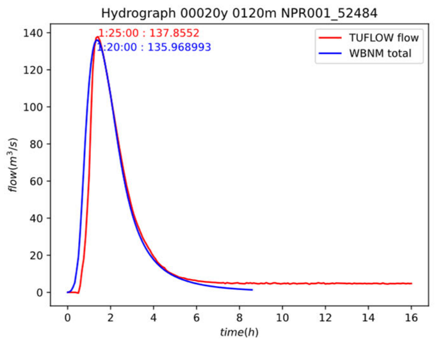
| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.92 | -3.5 | -5.0 |
| 5-year 120-minute | 0.96 | -2.7 | -5.0 |
| 5-year 360-minute | 0.98 | 0.3 | -5.0 |
| 20-year 60-minute | 0.94 | -3.0 | -5.0 |
| 20-year 120-minute | 0.97 | -3.0 | -5.0 |
| 20-year 360-minute | 0.98 | 0.2 | -5.0 |
| 100-year 60-minute | 0.95 | -2.7 | -5.0 |
| 100-year 120-minute | 0.97 | -2.5 | 0.0 |
| 100-year 360-minute | 0.99 | 0.6 | -5.0 |
| 2000-year 60-minute | 0.97 | -0.3 | -5.0 |
| 2000-year 120-minute | 0.99 | -0.2 | -5.0 |
| 2000-year 360-minute | 0.99 | 0.0 | -5.0 |

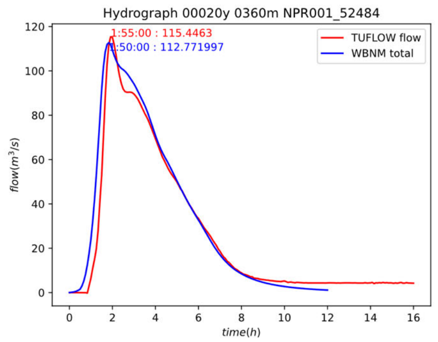


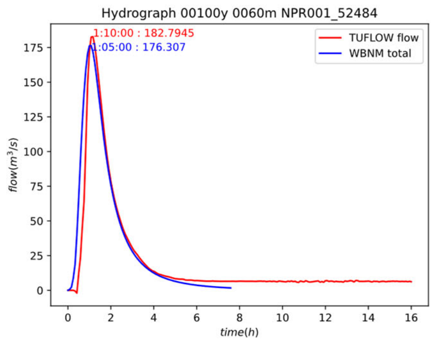



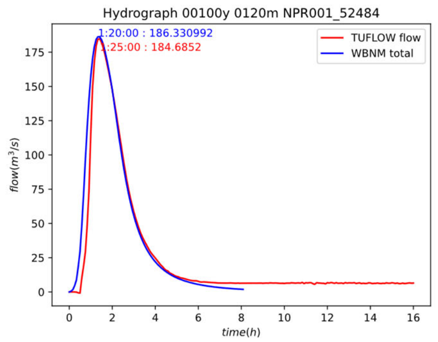



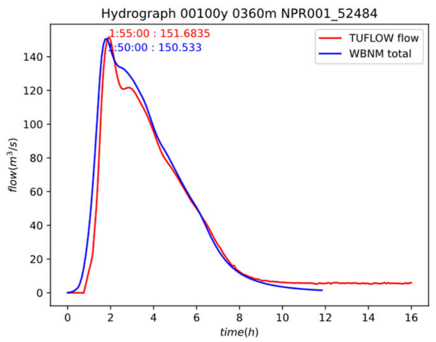



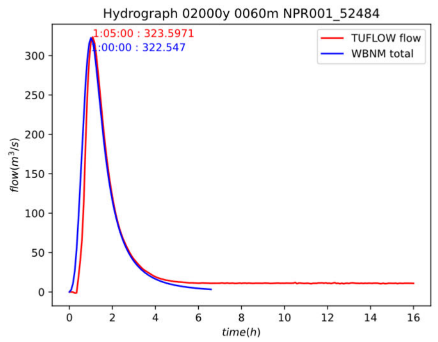



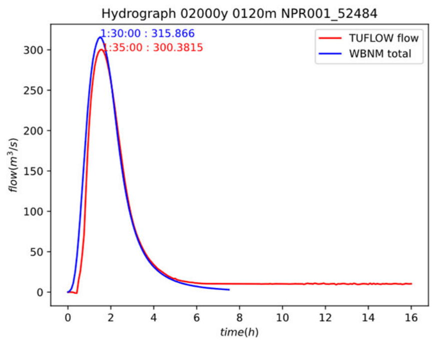



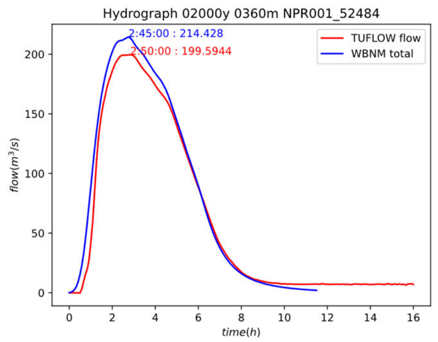



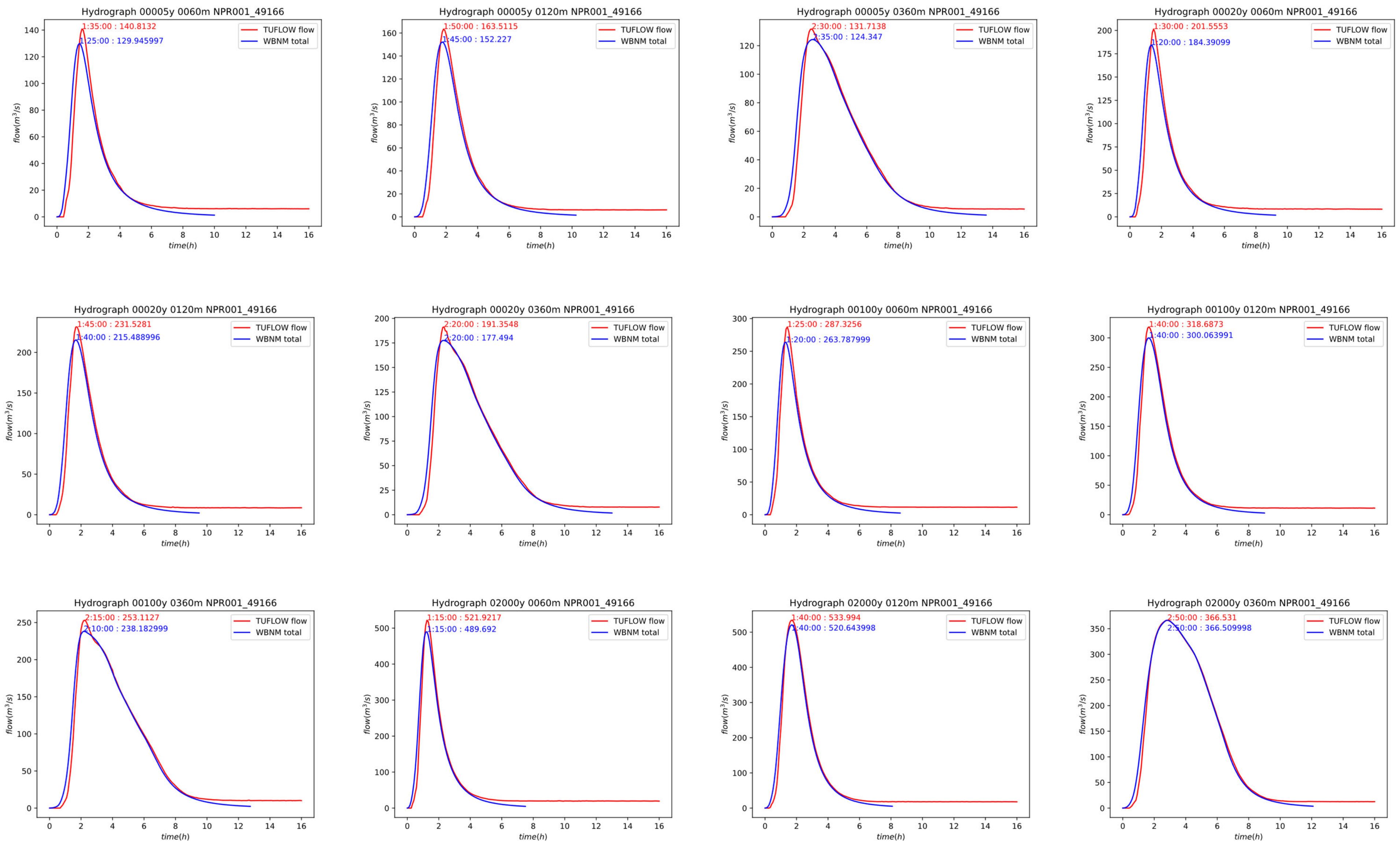



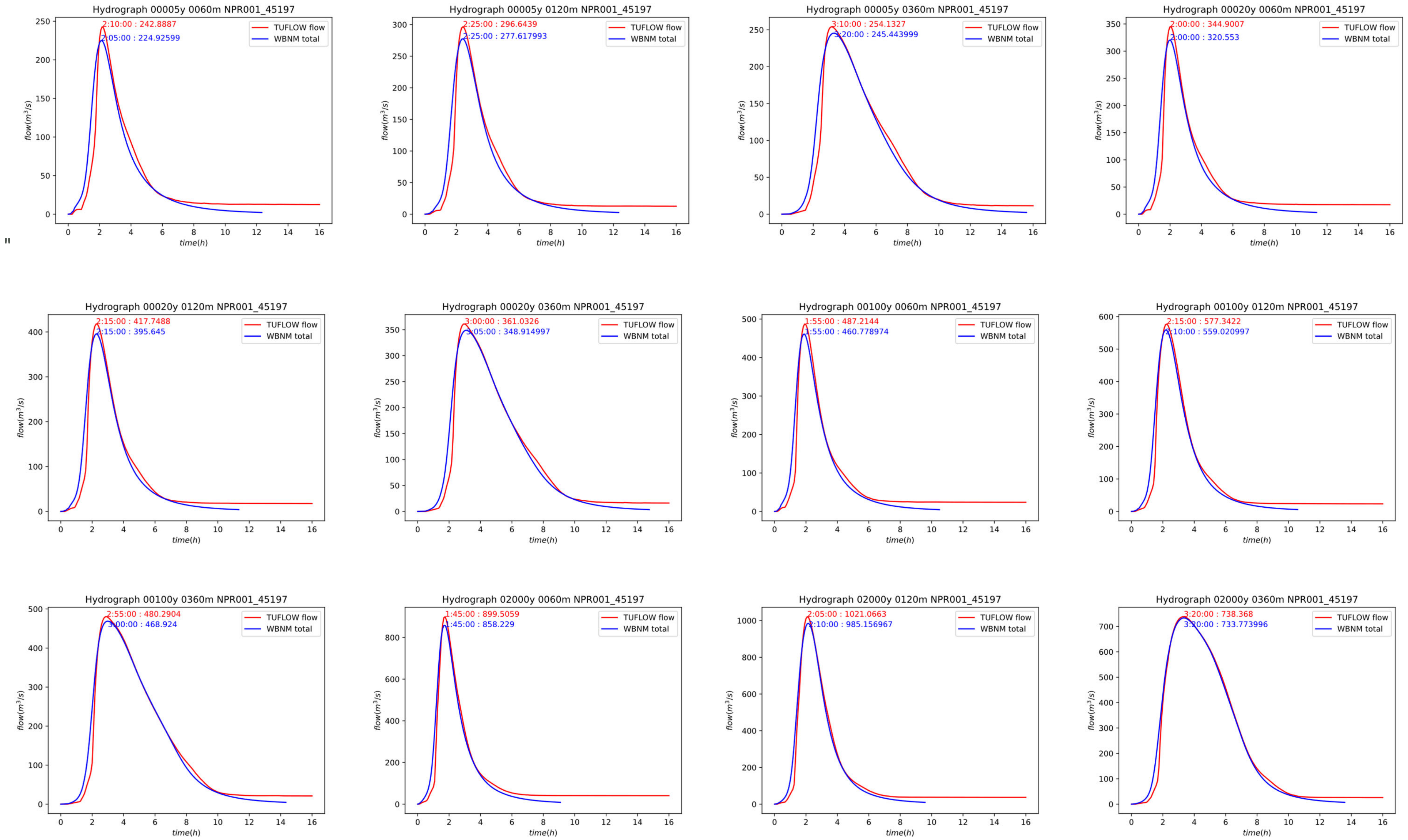



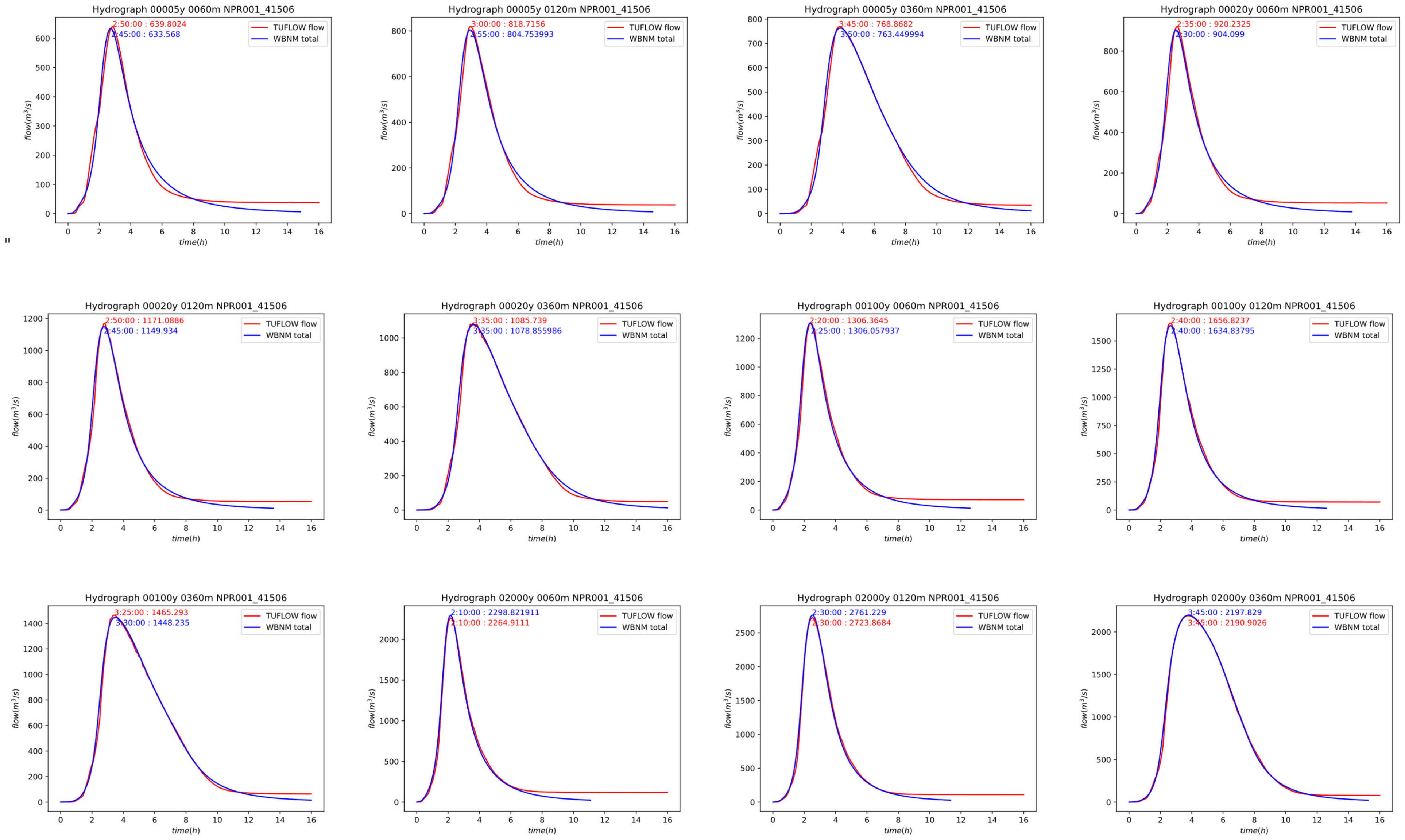

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.87 | -6.2 | -10.0 |
| 5-year 120-minute | 0.92 | -1.8 | -5.0 |
| 5-year 360-minute | 0.94 | -2.7 | -10.0 |
| 20-year 60-minute | 0.88 | -5.6 | -5.0 |
| 20-year 120-minute | 0.92 | -1.4 | -5.0 |
| 20-year 360-minute | 0.95 | -2.3 | -5.0 |
| 100-year 60-minute | 0.90 | -3.5 | -5.0 |
| 100-year 120-minute | 0.94 | 0.9 | -5.0 |
| 100-year 360-minute | 0.96 | -0.8 | -5.0 |
| 2000-year 60-minute | 0.93 | -0.3 | -5.0 |
| 2000-year 120-minute | 0.96 | 5.2 | -5.0 |
| 2000-year 360-minute | 0.98 | 7.4 | -5.0 |



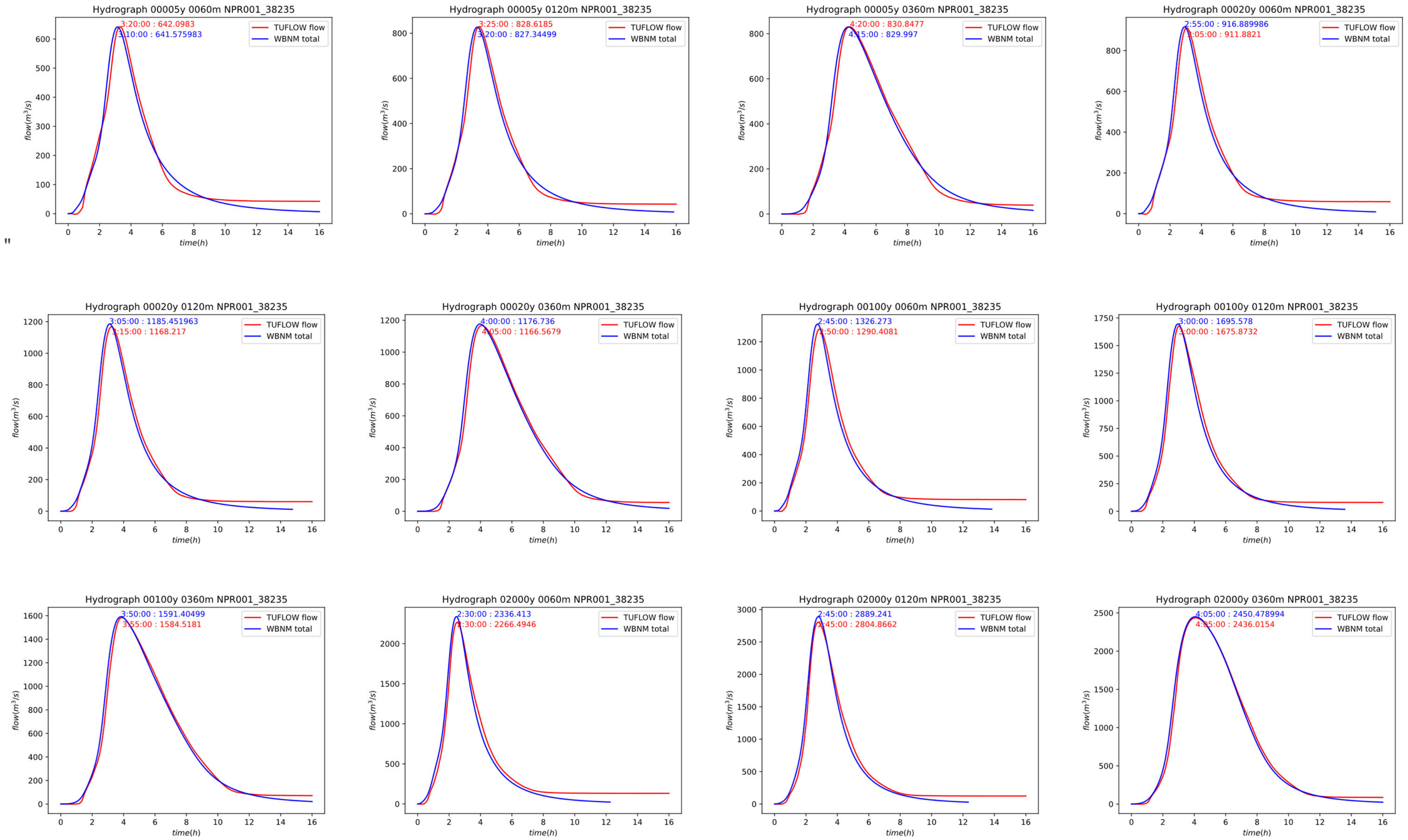

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | -7.7 | -10.0 |
| 5-year 120-minute | 0.96 | -6.9 | -5.0 |
| 5-year 360-minute | 0.98 | -5.6 | 5.0 |
| 20-year 60-minute | 0.94 | -8.5 | -10.0 |
| 20-year 120-minute | 0.97 | -6.9 | -5.0 |
| 20-year 360-minute | 0.98 | -7.2 | 0.0 |
| 100-year 60-minute | 0.95 | -8.2 | -5.0 |
| 100-year 120-minute | 0.97 | -5.8 | 0.0 |
| 100-year 360-minute | 0.98 | -5.9 | -5.0 |
| 2000-year 60-minute | 0.97 | -6.2 | 0.0 |
| 2000-year 120-minute | 0.99 | -2.5 | 0.0 |
| 2000-year 360-minute | 0.99 | 0.0 | 0.0 |



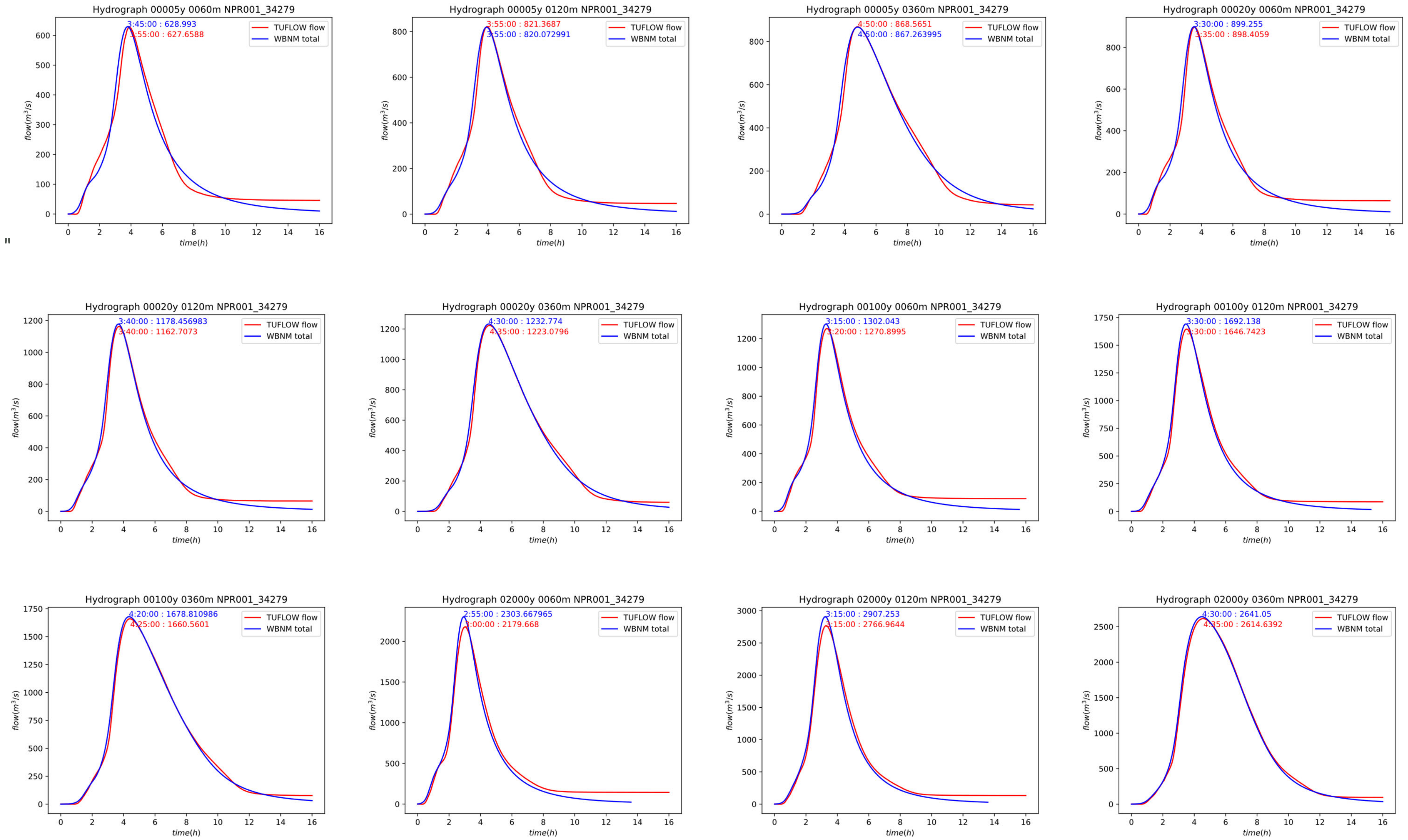

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.92 | -7.4 | -5.0 |
| 5-year 120-minute | 0.95 | -6.4 | 0.0 |
| 5-year 360-minute | 0.97 | -3.4 | 10.0 |
| 20-year 60-minute | 0.94 | -7.1 | 0.0 |
| 20-year 120-minute | 0.96 | -5.3 | 0.0 |
| 20-year 360-minute | 0.97 | -3.4 | 5.0 |
| 100-year 60-minute | 0.95 | -5.4 | 0.0 |
| 100-year 120-minute | 0.97 | -3.2 | -5.0 |
| 100-year 360-minute | 0.98 | -2.4 | 5.0 |
| 2000-year 60-minute | 0.97 | -4.6 | 0.0 |
| 2000-year 120-minute | 0.98 | -3.5 | 5.0 |
| 2000-year 360-minute | 0.99 | -0.6 | 0.0 |



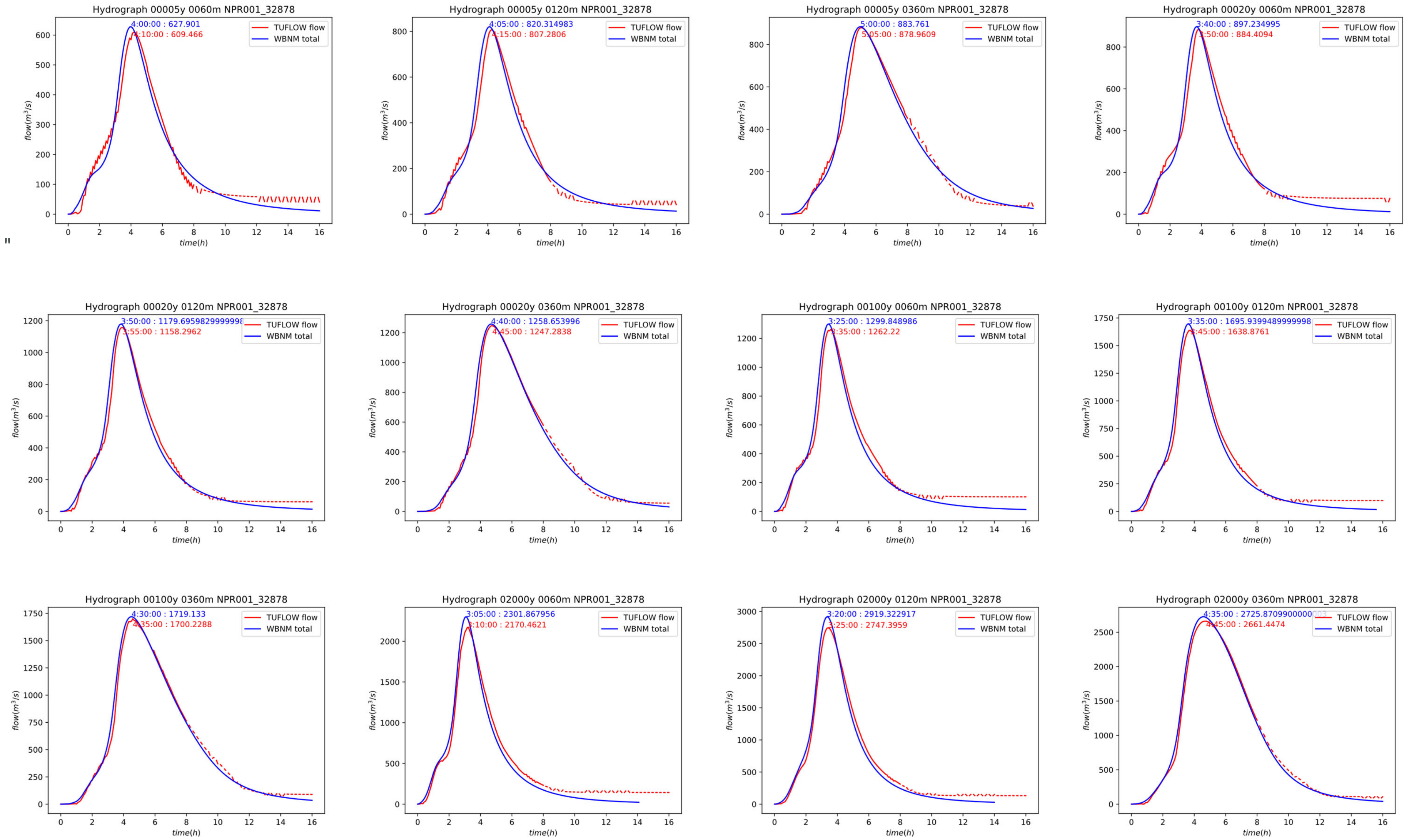

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | -1.0 | -5.0 |
| 5-year 120-minute | 0.99 | -1.7 | -5.0 |
| 5-year 360-minute | 0.99 | -0.7 | 5.0 |
| 20-year 60-minute | 0.99 | -1.8 | -5.0 |
| 20-year 120-minute | 0.99 | -1.8 | -5.0 |
| 20-year 360-minute | 0.99 | -0.6 | 0.0 |
| 100-year 60-minute | 0.99 | 0.0 | 5.0 |
| 100-year 120-minute | 0.99 | -1.3 | 0.0 |
| 100-year 360-minute | 1.00 | -1.2 | 5.0 |
| 2000-year 60-minute | 0.99 | 1.5 | 0.0 |
| 2000-year 120-minute | 1.00 | 1.4 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.3 | 0.0 |



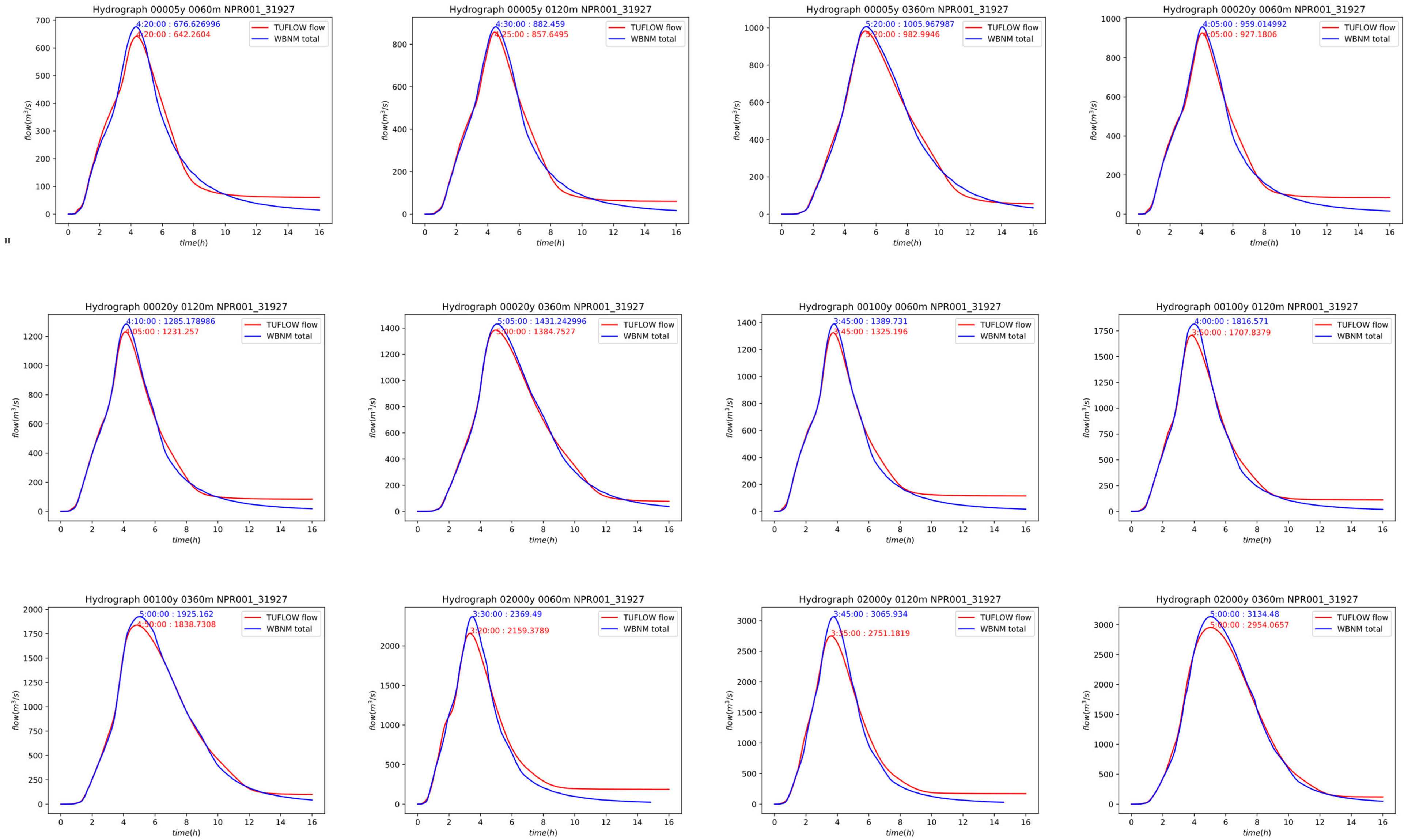

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | -0.1 | -10.0 |
| 5-year 120-minute | 0.98 | -0.2 | -5.0 |
| 5-year 360-minute | 0.99 | -0.1 | -5.0 |
| 20-year 60-minute | 0.98 | 0.5 | -10.0 |
| 20-year 120-minute | 0.98 | 1.5 | -10.0 |
| 20-year 360-minute | 0.99 | 0.9 | -5.0 |
| 100-year 60-minute | 0.98 | 2.8 | -5.0 |
| 100-year 120-minute | 0.98 | 1.2 | 0.0 |
| 100-year 360-minute | 0.99 | 0.4 | -5.0 |
| 2000-year 60-minute | 0.98 | 3.1 | 0.0 |
| 2000-year 120-minute | 0.99 | 3.0 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.6 | 0.0 |



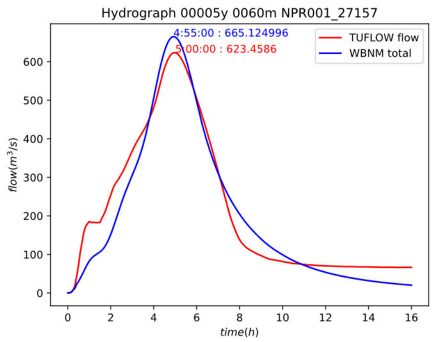

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.97 | 0.2 | -10.0 |
| 5-year 120-minute | 0.99 | -0.2 | 0.0 |
| 5-year 360-minute | 0.99 | -0.1 | 0.0 |
| 20-year 60-minute | 0.98 | 0.1 | -5.0 |
| 20-year 120-minute | 0.99 | 1.4 | 0.0 |
| 20-year 360-minute | 1.00 | 0.8 | -5.0 |
| 100-year 60-minute | 0.98 | 2.5 | -5.0 |
| 100-year 120-minute | 0.99 | 2.8 | 0.0 |
| 100-year 360-minute | 1.00 | 1.1 | -5.0 |
| 2000-year 60-minute | 0.98 | 5.7 | -5.0 |
| 2000-year 120-minute | 0.99 | 5.1 | 0.0 |
| 2000-year 360-minute | 1.00 | 1.0 | -5.0 |

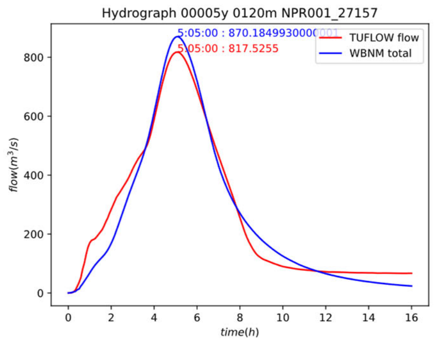


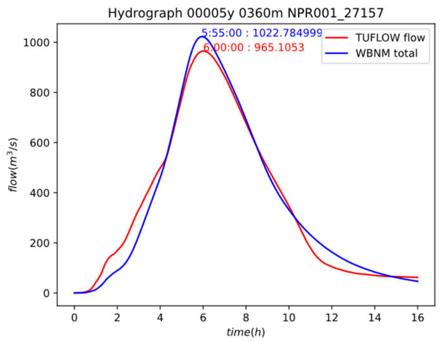

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.97 | 3.0 | -10.0 |
| 5-year 120-minute | 0.97 | 1.6 | -10.0 |
| 5-year 360-minute | 0.99 | 0.5 | -5.0 |
| 20-year 60-minute | 0.96 | 1.5 | -10.0 |
| 20-year 120-minute | 0.98 | 1.8 | -5.0 |
| 20-year 360-minute | 0.99 | 0.9 | -5.0 |
| 100-year 60-minute | 0.97 | 3.0 | -10.0 |
| 100-year 120-minute | 0.98 | 3.5 | -10.0 |
| 100-year 360-minute | 0.99 | 1.1 | -5.0 |
| 2000-year 60-minute | 0.98 | 6.1 | -5.0 |
| 2000-year 120-minute | 0.99 | 6.3 | -5.0 |
| 2000-year 360-minute | 1.00 | 2.4 | -10.0 |

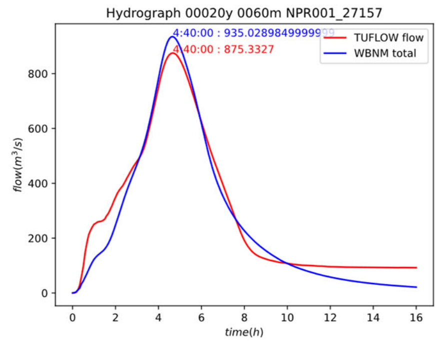


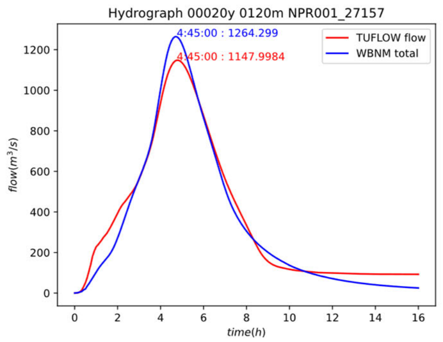

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | 5.4 | 0.0 |
| 5-year 120-minute | 0.99 | 2.9 | 5.0 |
| 5-year 360-minute | 1.00 | 2.3 | 0.0 |
| 20-year 60-minute | 0.98 | 3.4 | 0.0 |
| 20-year 120-minute | 0.99 | 4.4 | 5.0 |
| 20-year 360-minute | 1.00 | 3.4 | 5.0 |
| 100-year 60-minute | 0.98 | 4.9 | 0.0 |
| 100-year 120-minute | 0.99 | 6.4 | 10.0 |
| 100-year 360-minute | 1.00 | 4.7 | 10.0 |
| 2000-year 60-minute | 0.97 | 9.7 | 10.0 |
| 2000-year 120-minute | 0.98 | 11.4 | 10.0 |
| 2000-year 360-minute | 1.00 | 6.1 | 0.0 |

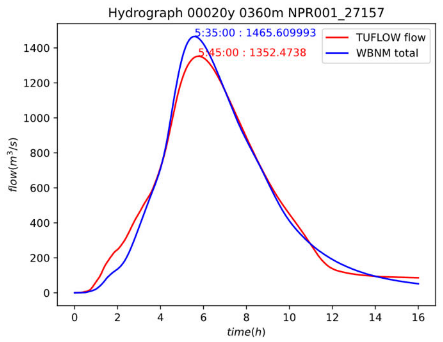


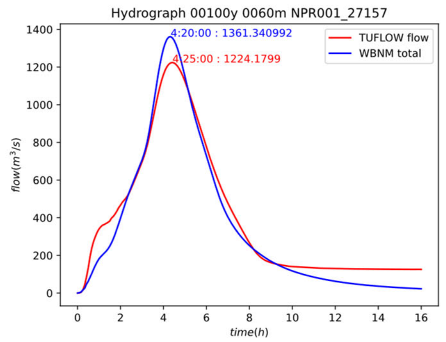



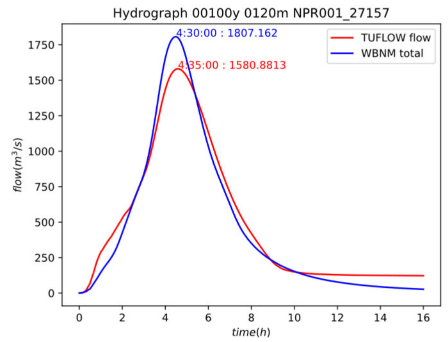



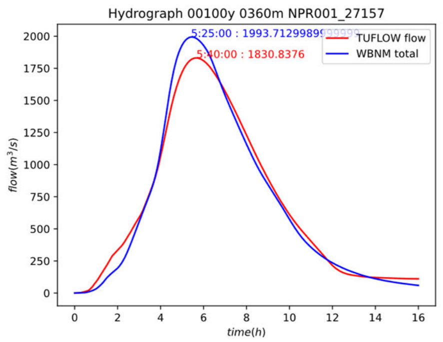



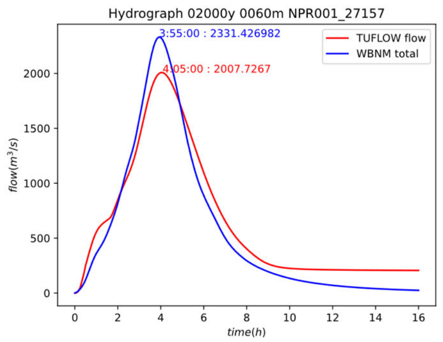



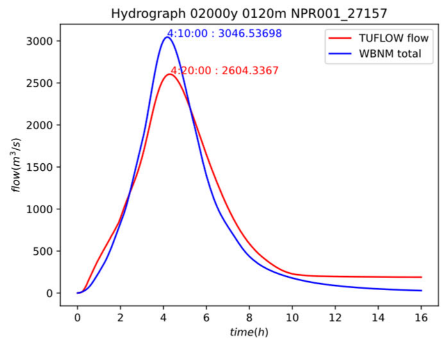



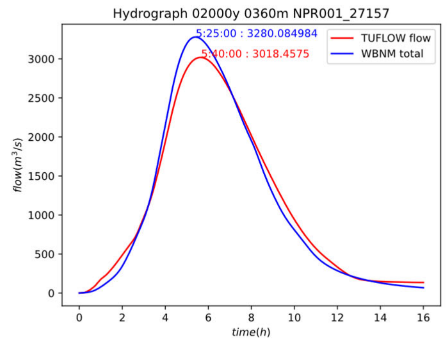



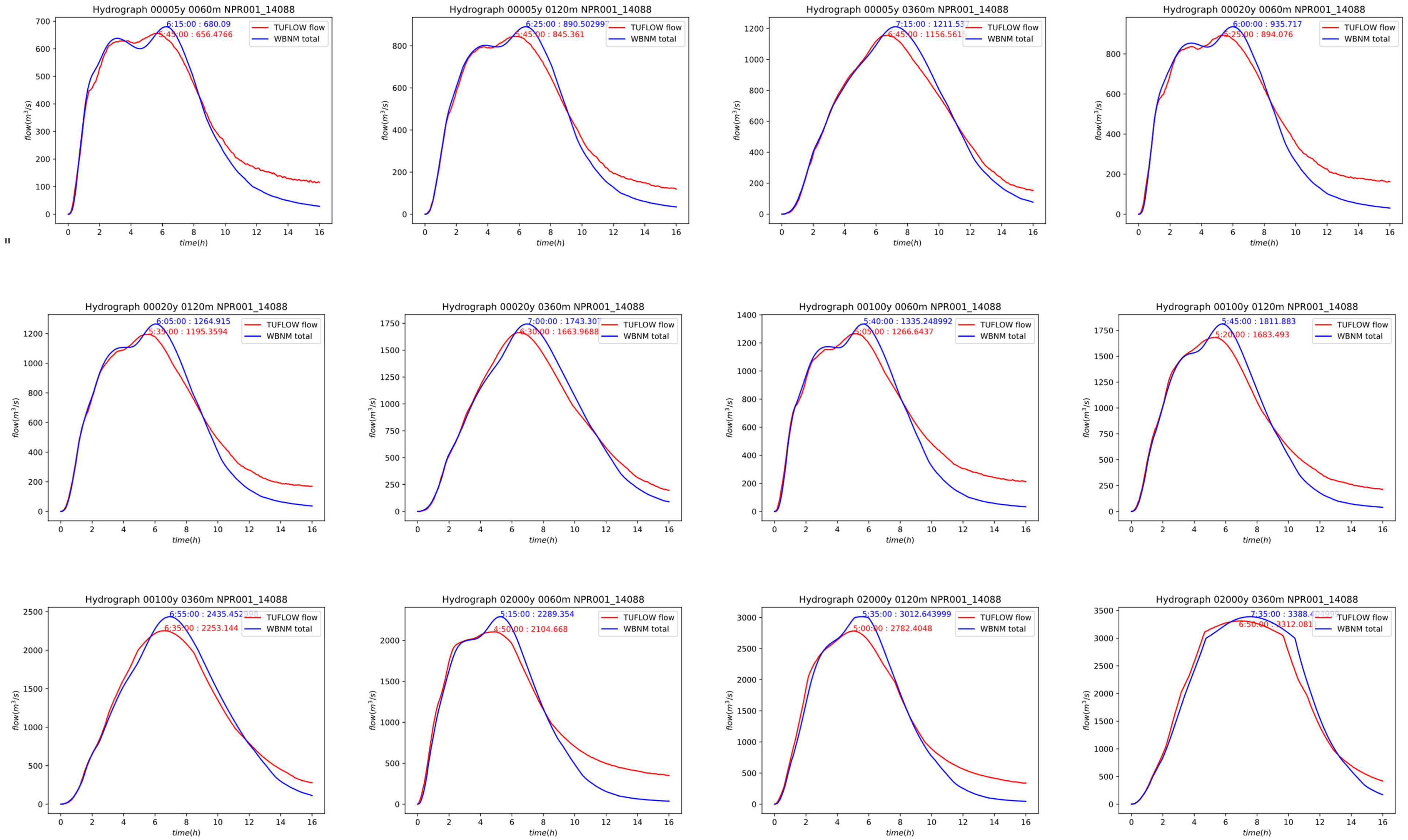



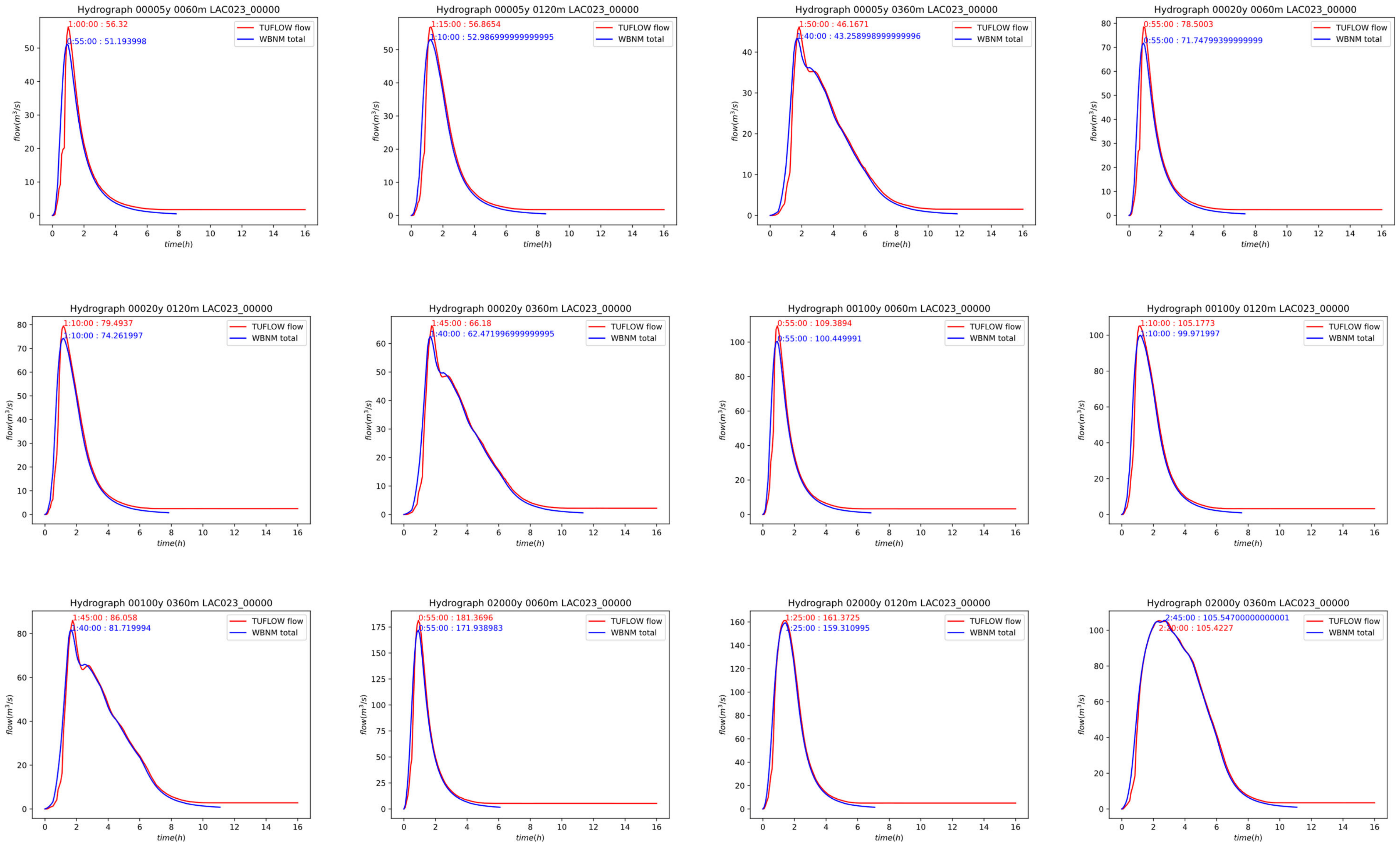



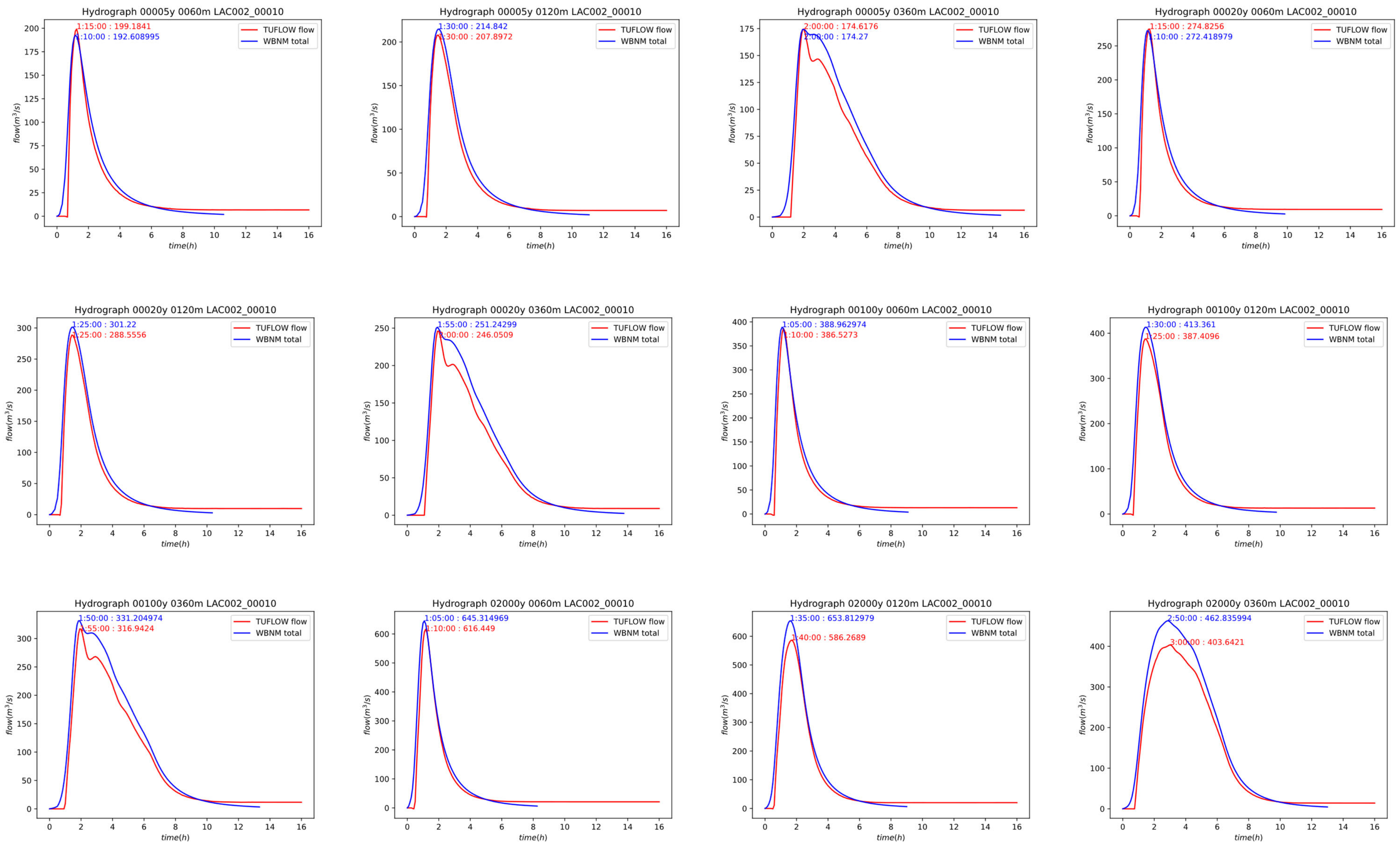

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | 6.7 | -5.0 |
| 5-year 120-minute | 0.96 | 6.4 | 0.0 |
| 5-year 360-minute | 0.98 | 6.0 | -5.0 |
| 20-year 60-minute | 0.95 | 6.8 | 0.0 |
| 20-year 120-minute | 0.97 | 10.1 | 0.0 |
| 20-year 360-minute | 0.98 | 8.4 | -10.0 |
| 100-year 60-minute | 0.95 | 11.2 | -5.0 |
| 100-year 120-minute | 0.96 | 14.3 | -5.0 |
| 100-year 360-minute | 0.98 | 8.9 | -15.0 |
| 2000-year 60-minute | 0.93 | 16.1 | -10.0 |
| 2000-year 120-minute | 0.95 | 17.0 | -10.0 |
| 2000-year 360-minute | 0.98 | 8.7 | -15.0 |



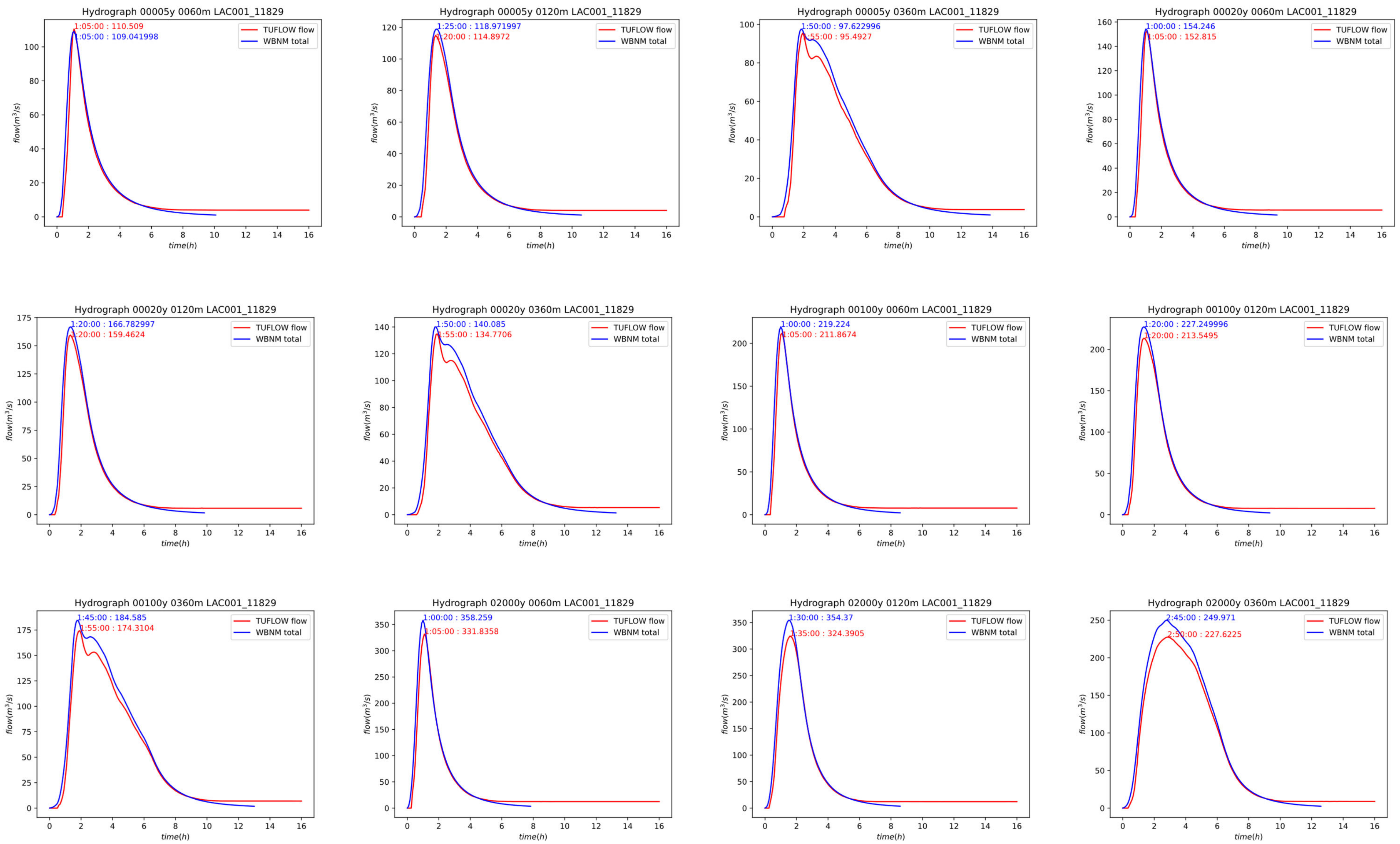

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | 3.6 | 30.0 |
| 5-year 120-minute | 0.96 | 5.3 | 40.0 |
| 5-year 360-minute | 0.98 | 4.8 | 30.0 |
| 20-year 60-minute | 0.92 | 4.7 | 35.0 |
| 20-year 120-minute | 0.95 | 5.8 | 30.0 |
| 20-year 360-minute | 0.97 | 4.8 | 30.0 |
| 100-year 60-minute | 0.90 | 5.4 | 35.0 |
| 100-year 120-minute | 0.94 | 7.6 | 25.0 |
| 100-year 360-minute | 0.98 | 8.1 | 20.0 |
| 2000-year 60-minute | 0.89 | 8.8 | 25.0 |
| 2000-year 120-minute | 0.94 | 8.3 | 35.0 |
| 2000-year 360-minute | 0.98 | 2.3 | 45.0 |



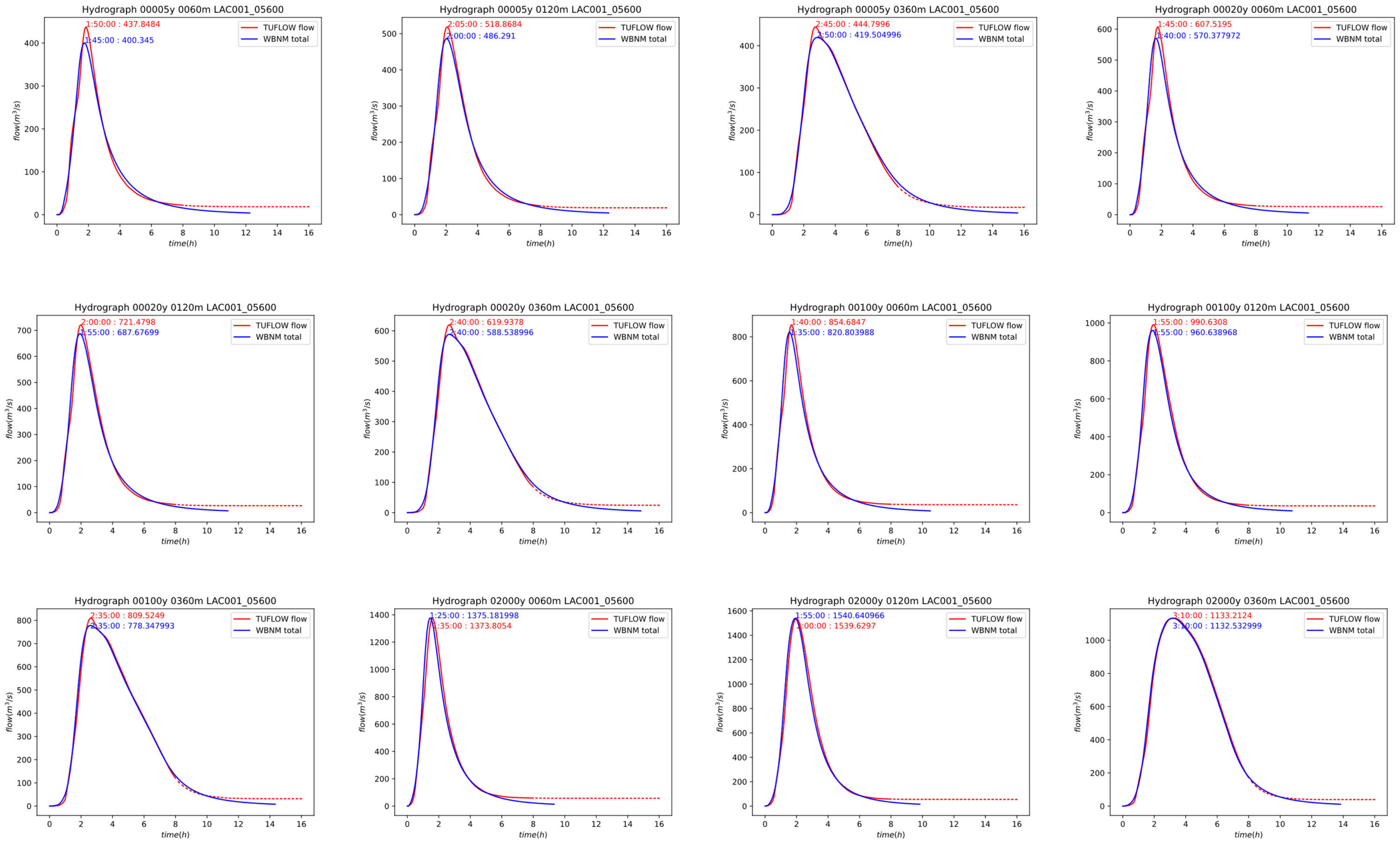

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.91 | -9.1 | -5.0 |
| 5-year 120-minute | 0.95 | -6.8 | -5.0 |
| 5-year 360-minute | 0.97 | -6.3 | -10.0 |
| 20-year 60-minute | 0.93 | -8.6 | 0.0 |
| 20-year 120-minute | 0.96 | -6.6 | 0.0 |
| 20-year 360-minute | 0.98 | -5.6 | -5.0 |
| 100-year 60-minute | 0.94 | -8.2 | 0.0 |
| 100-year 120-minute | 0.97 | -4.9 | 0.0 |
| 100-year 360-minute | 0.99 | -5.0 | -5.0 |
| 2000-year 60-minute | 0.97 | -5.2 | 0.0 |
| 2000-year 120-minute | 0.99 | -1.3 | 0.0 |
| 2000-year 360-minute | 0.99 | 0.1 | 25.0 |



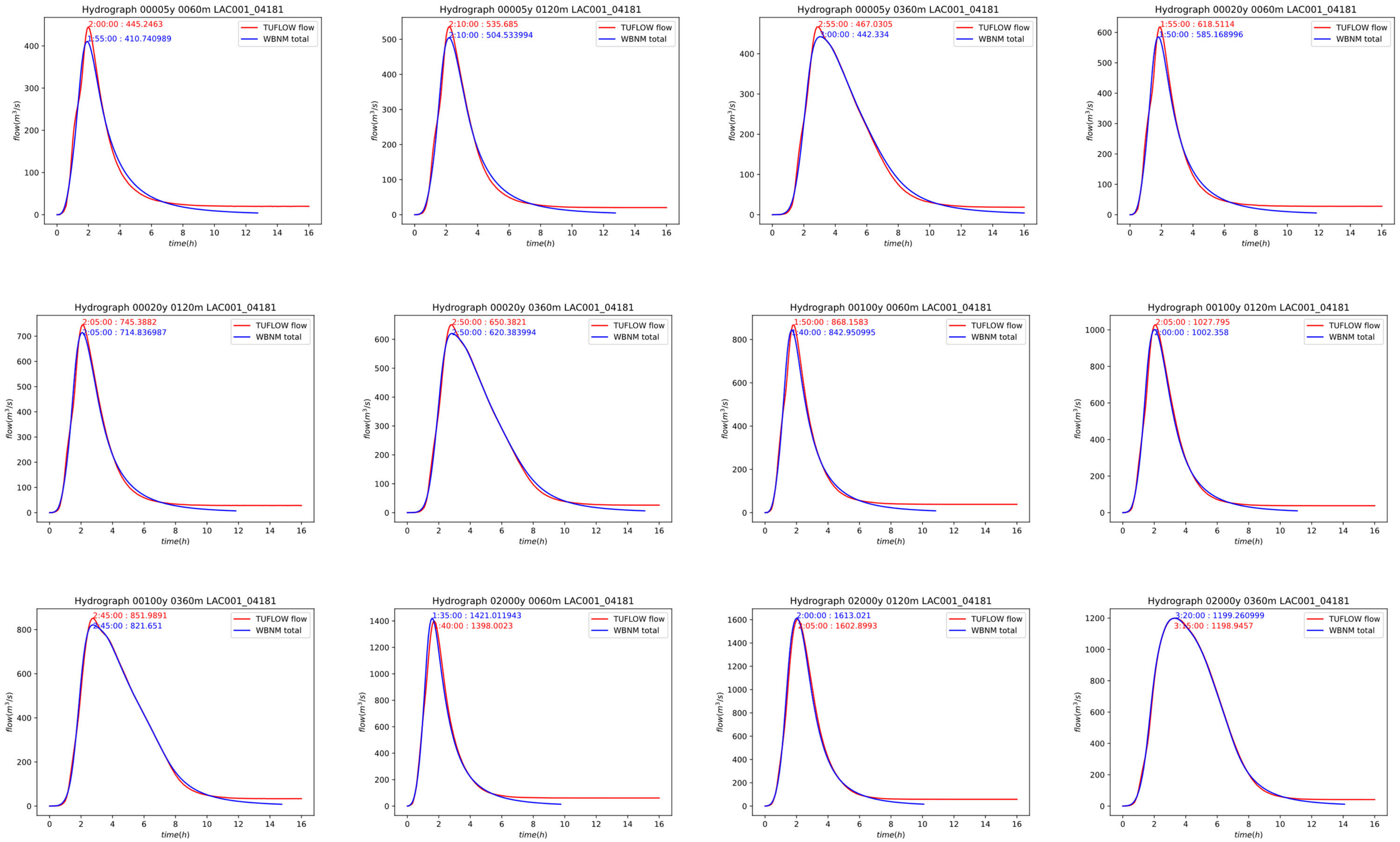

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.93 | -3.3 | -5.0 |
| 5-year 120-minute | 0.95 | 3.3 | 0.0 |
| 5-year 360-minute | 0.95 | -0.2 | 0.0 |
| 20-year 60-minute | 0.94 | -0.9 | -5.0 |
| 20-year 120-minute | 0.96 | 4.4 | 0.0 |
| 20-year 360-minute | 0.95 | 2.1 | -5.0 |
| 100-year 60-minute | 0.94 | 0.6 | -5.0 |
| 100-year 120-minute | 0.96 | 6.7 | 5.0 |
| 100-year 360-minute | 0.96 | 4.5 | -5.0 |
| 2000-year 60-minute | 0.95 | 4.7 | -5.0 |
| 2000-year 120-minute | 0.96 | 11.5 | -5.0 |
| 2000-year 360-minute | 0.96 | 14.7 | -10.0 |



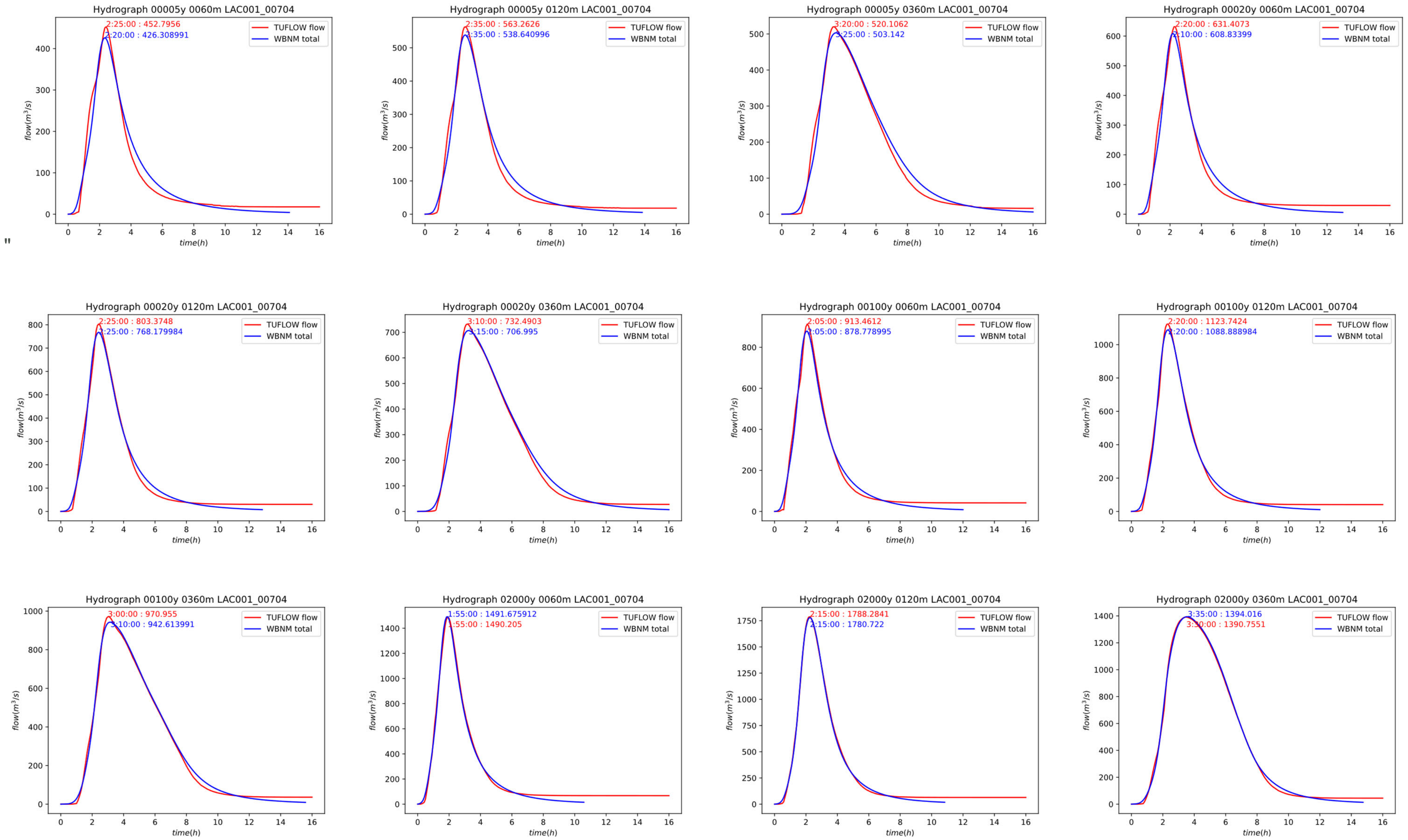

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | -1.3 | 0.0 |
| 5-year 120-minute | 0.97 | 3.5 | 5.0 |
| 5-year 360-minute | 0.98 | 2.2 | -5.0 |
| 20-year 60-minute | 0.96 | 0.9 | -5.0 |
| 20-year 120-minute | 0.97 | 4.6 | 0.0 |
| 20-year 360-minute | 0.98 | 3.9 | -5.0 |
| 100-year 60-minute | 0.96 | 3.5 | -5.0 |
| 100-year 120-minute | 0.98 | 6.4 | 0.0 |
| 100-year 360-minute | 0.98 | 5.9 | -10.0 |
| 2000-year 60-minute | 0.96 | 8.0 | -5.0 |
| 2000-year 120-minute | 0.98 | 9.2 | -5.0 |
| 2000-year 360-minute | 0.98 | 9.8 | -5.0 |



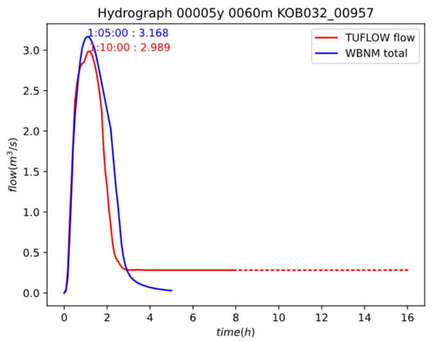

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.98 | -8.6 | -5.0 |
| 5-year 120-minute | 0.99 | -6.3 | -5.0 |
| 5-year 360-minute | 1.00 | -5.7 | 5.0 |
| 20-year 60-minute | 0.98 | -6.1 | -5.0 |
| 20-year 120-minute | 0.99 | -4.7 | -5.0 |
| 20-year 360-minute | 1.00 | -5.1 | 0.0 |
| 100-year 60-minute | 0.98 | -4.0 | -5.0 |
| 100-year 120-minute | 0.99 | -3.0 | 0.0 |
| 100-year 360-minute | 1.00 | -3.9 | 0.0 |
| 2000-year 60-minute | 0.98 | 0.1 | -10.0 |
| 2000-year 120-minute | 0.99 | 0.1 | -5.0 |
| 2000-year 360-minute | 1.00 | -0.1 | 0.0 |

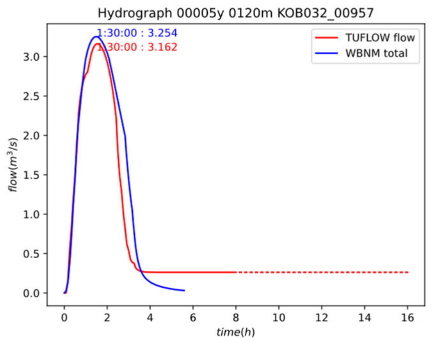


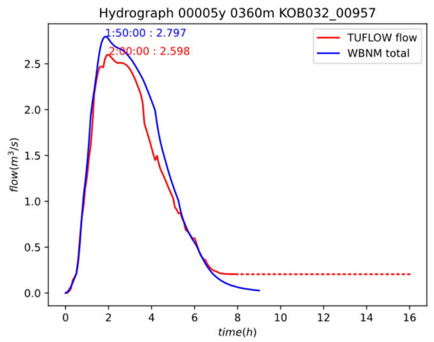

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.99 | -7.7 | -5.0 |
| 5-year 120-minute | 0.99 | -5.8 | 0.0 |
| 5-year 360-minute | 1.00 | -5.3 | 5.0 |
| 20-year 60-minute | 0.99 | -5.4 | -5.0 |
| 20-year 120-minute | 0.99 | -4.1 | 0.0 |
| 20-year 360-minute | 1.00 | -4.6 | 0.0 |
| 100-year 60-minute | 0.99 | -2.9 | -10.0 |
| 100-year 120-minute | 0.99 | -2.5 | -5.0 |
| 100-year 360-minute | 1.00 | -3.6 | 0.0 |
| 2000-year 60-minute | 0.99 | 1.6 | -5.0 |
| 2000-year 120-minute | 0.99 | 0.6 | -5.0 |
| 2000-year 360-minute | 1.00 | 0.0 | 5.0 |

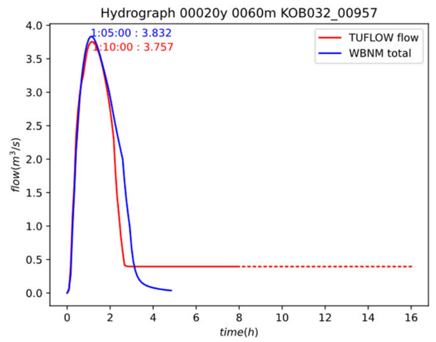


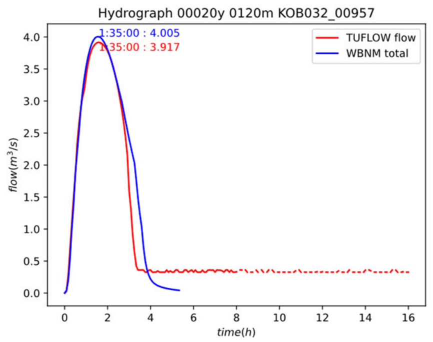

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.97 | -5.8 | -5.0 |
| 5-year 120-minute | 0.99 | -4.4 | 0.0 |
| 5-year 360-minute | 0.99 | -3.3 | 5.0 |
| 20-year 60-minute | 0.98 | -3.6 | -10.0 |
| 20-year 120-minute | 0.99 | -4.4 | 0.0 |
| 20-year 360-minute | 0.99 | -3.5 | 5.0 |
| 100-year 60-minute | 0.99 | -3.8 | 0.0 |
| 100-year 120-minute | 1.00 | -3.1 | 0.0 |
| 100-year 360-minute | 1.00 | -2.9 | 10.0 |
| 2000-year 60-minute | 1.00 | 0.1 | 0.0 |
| 2000-year 120-minute | 1.00 | -0.4 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.2 | 5.0 |

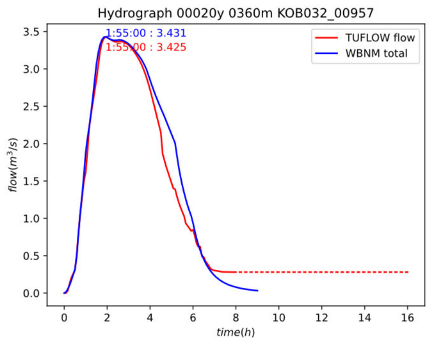


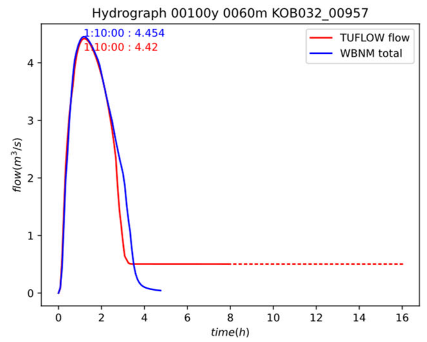



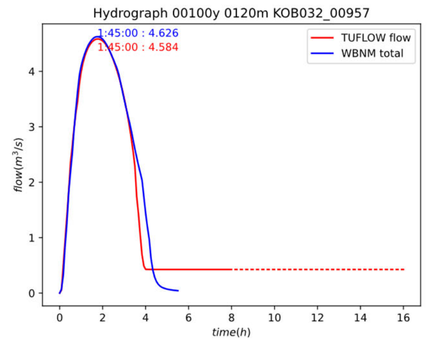



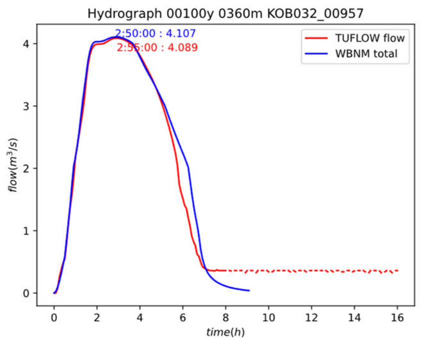



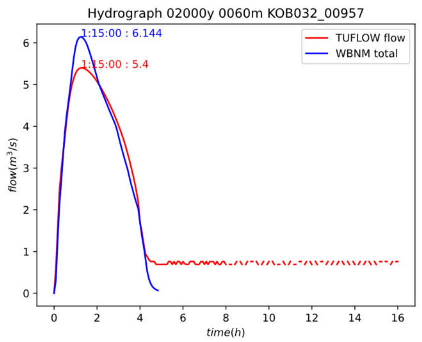



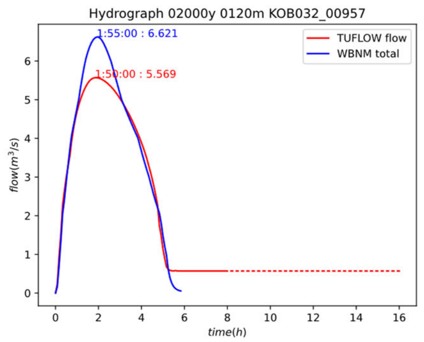



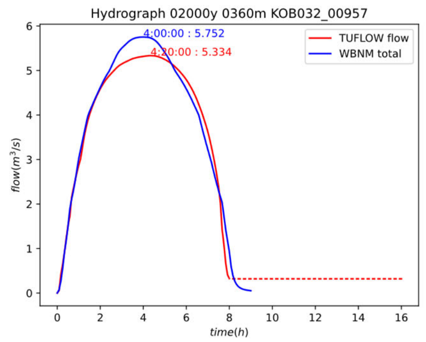



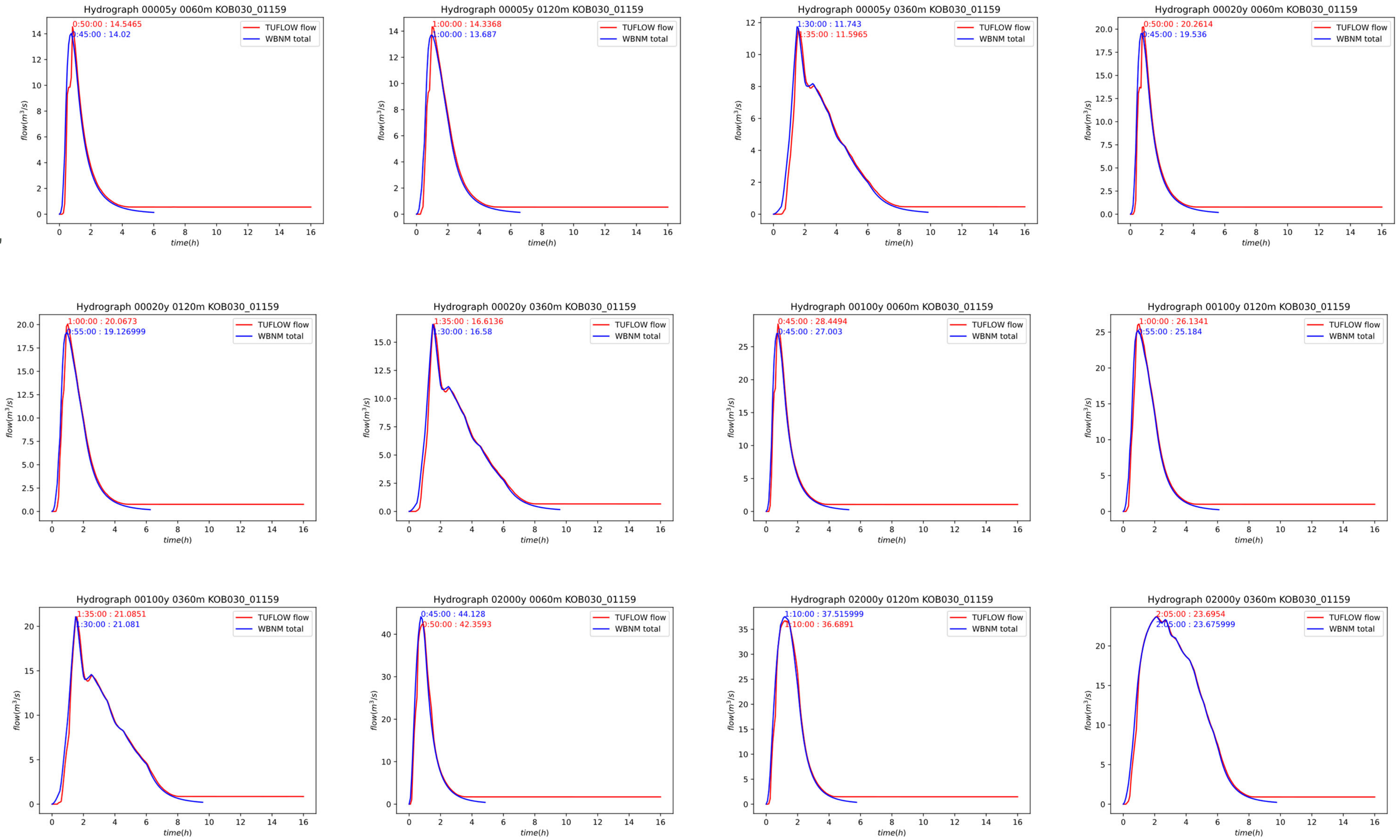



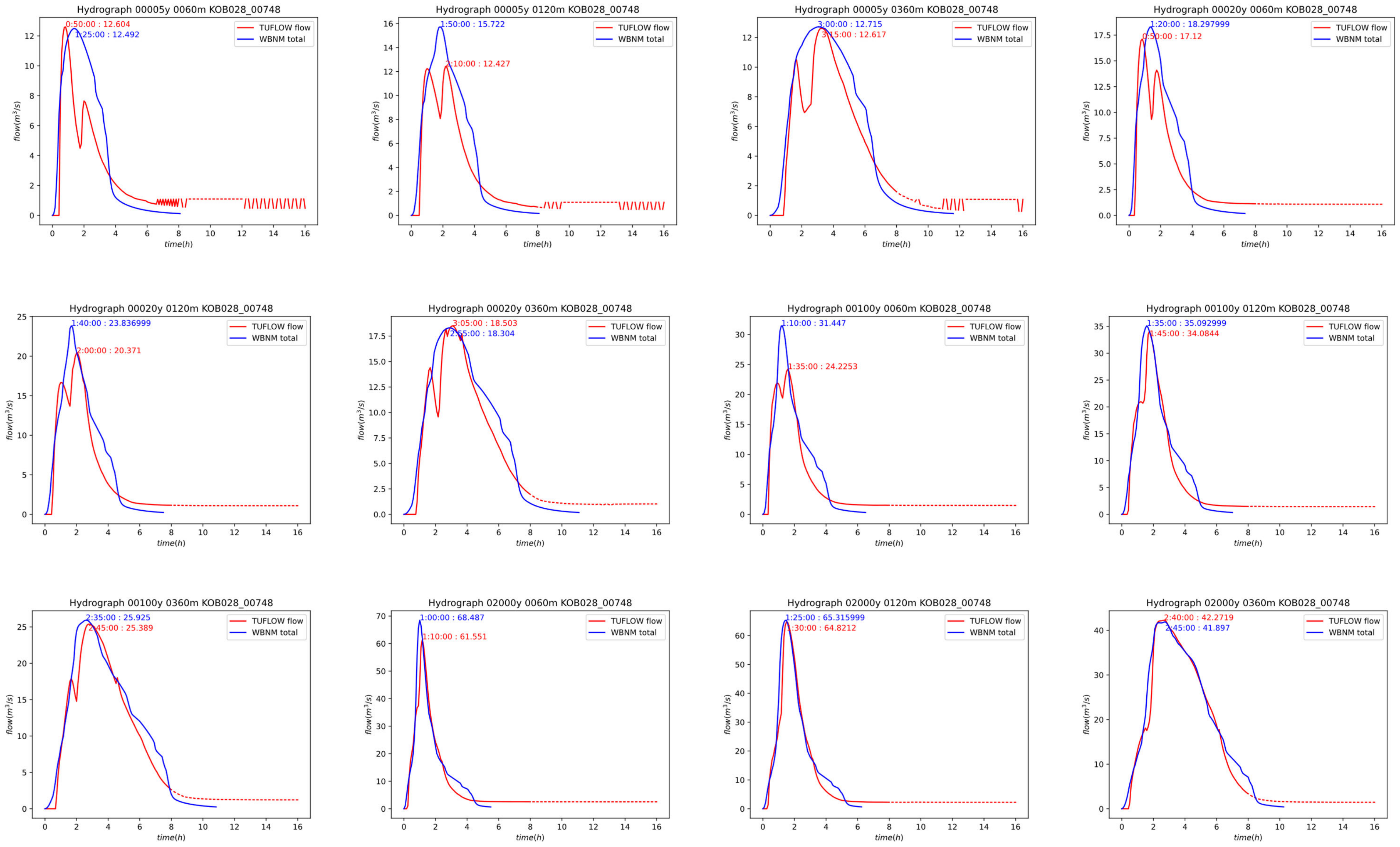



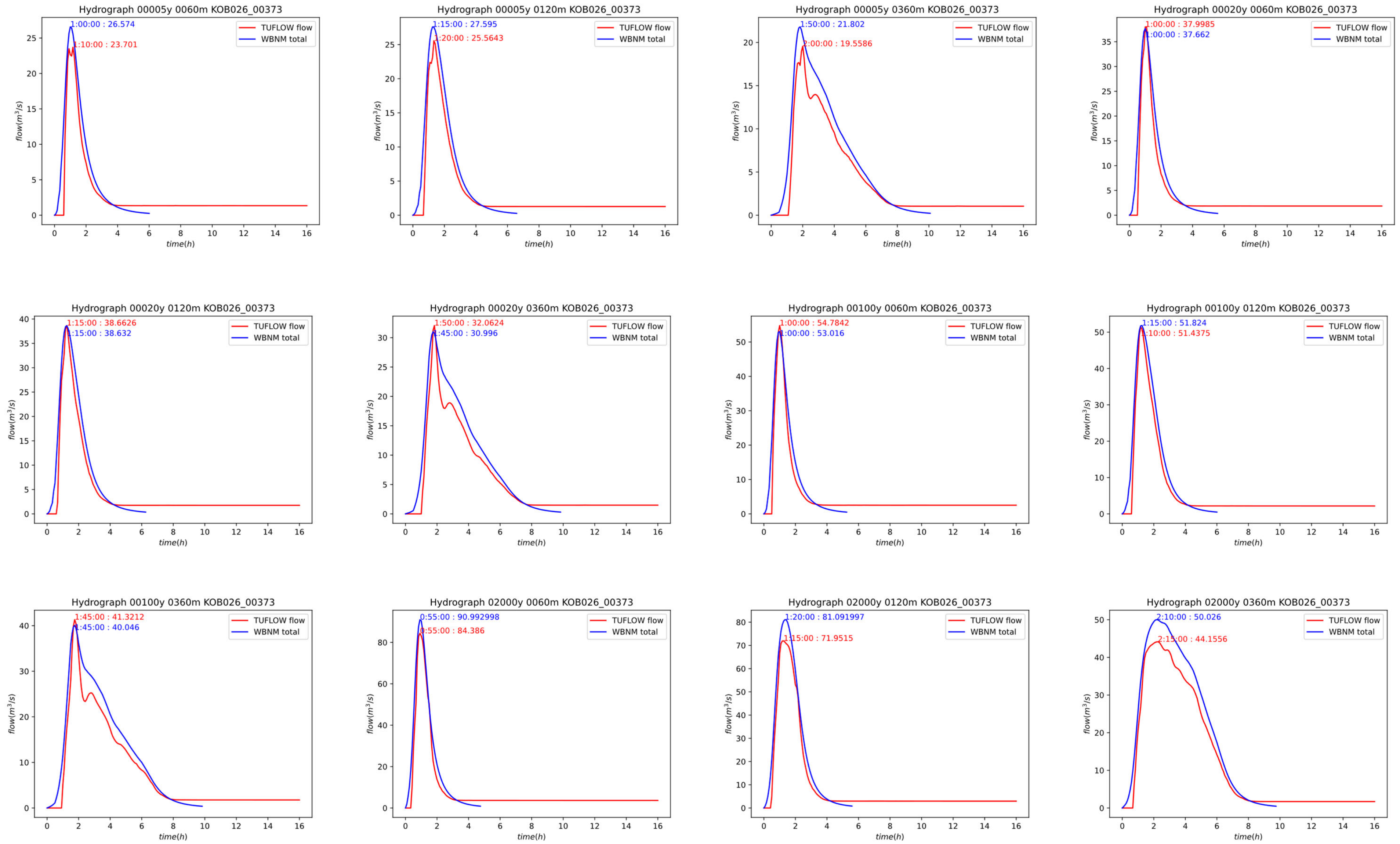

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.89 | 6.0 | -5.0 |
| 5-year 120-minute | 0.93 | 2.9 | 0.0 |
| 5-year 360-minute | 0.97 | 7.7 | -10.0 |
| 20-year 60-minute | 0.92 | 2.0 | -5.0 |
| 20-year 120-minute | 0.95 | 2.2 | 0.0 |
| 20-year 360-minute | 0.97 | 0.2 | 0.0 |
| 100-year 60-minute | 0.96 | 0.8 | 0.0 |
| 100-year 120-minute | 0.97 | 0.9 | 0.0 |
| 100-year 360-minute | 0.98 | 0.4 | -5.0 |
| 2000-year 60-minute | 0.98 | 13.8 | 0.0 |
| 2000-year 120-minute | 0.97 | 18.9 | 5.0 |
| 2000-year 360-minute | 0.99 | 7.8 | -20.0 |



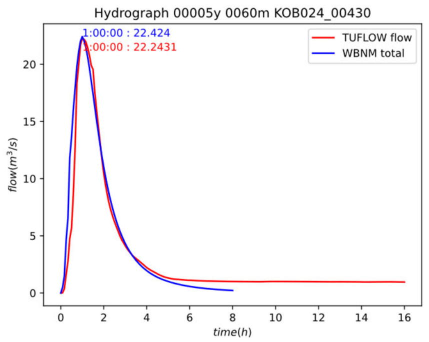

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.93 | -3.6 | -5.0 |
| 5-year 120-minute | 0.96 | -4.5 | 0.0 |
| 5-year 360-minute | 0.97 | 1.3 | -5.0 |
| 20-year 60-minute | 0.95 | -3.6 | -5.0 |
| 20-year 120-minute | 0.97 | -4.7 | -5.0 |
| 20-year 360-minute | 0.98 | -0.2 | -5.0 |
| 100-year 60-minute | 0.97 | -5.1 | 0.0 |
| 100-year 120-minute | 0.98 | -3.6 | -5.0 |
| 100-year 360-minute | 0.99 | 0.0 | -5.0 |
| 2000-year 60-minute | 0.98 | 4.2 | -5.0 |
| 2000-year 120-minute | 0.99 | 2.3 | 0.0 |
| 2000-year 360-minute | 0.99 | -0.1 | 0.0 |

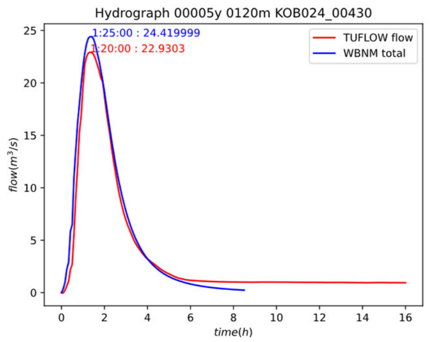


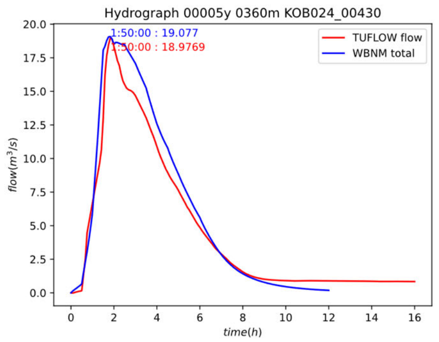

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.48 | -0.9 | 35.0 |
| 5-year 120-minute | 0.74 | 26.5 | -20.0 |
| 5-year 360-minute | 0.85 | 0.8 | -15.0 |
| 20-year 60-minute | 0.75 | 6.9 | 30.0 |
| 20-year 120-minute | 0.86 | 17.0 | -20.0 |
| 20-year 360-minute | 0.92 | -1.1 | -10.0 |
| 100-year 60-minute | 0.85 | 29.8 | -25.0 |
| 100-year 120-minute | 0.91 | 3.0 | -10.0 |
| 100-year 360-minute | 0.95 | 2.1 | -10.0 |
| 2000-year 60-minute | 0.91 | 11.3 | -10.0 |
| 2000-year 120-minute | 0.95 | 0.8 | -5.0 |
| 2000-year 360-minute | 0.97 | -0.9 | 5.0 |

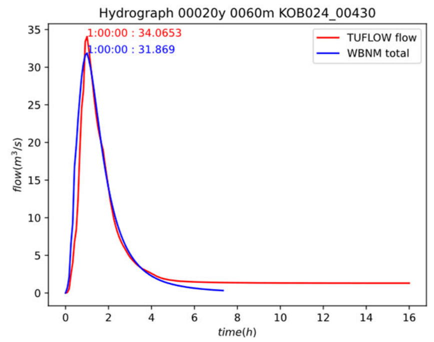



| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.86 | 12.1 | -10.0 |
| 5-year 120-minute | 0.90 | 7.9 | -5.0 |
| 5-year 360-minute | 0.89 | 11.5 | -10.0 |
| 20-year 60-minute | 0.91 | -0.9 | 0.0 |
| 20-year 120-minute | 0.93 | -0.1 | 0.0 |
| 20-year 360-minute | 0.92 | -3.3 | -5.0 |
| 100-year 60-minute | 0.92 | -3.2 | 0.0 |
| 100-year 120-minute | 0.94 | 0.8 | 5.0 |
| 100-year 360-minute | 0.93 | -3.1 | 0.0 |
| 2000-year 60-minute | 0.95 | 7.8 | 0.0 |
| 2000-year 120-minute | 0.96 | 12.7 | 5.0 |
| 2000-year 360-minute | 0.95 | 13.3 | -5.0 |

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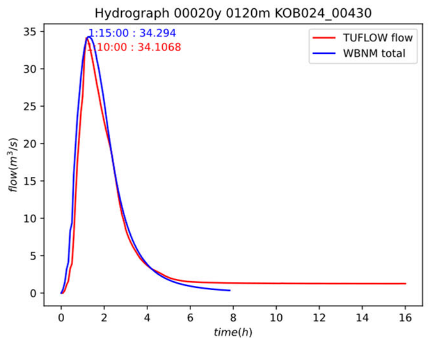
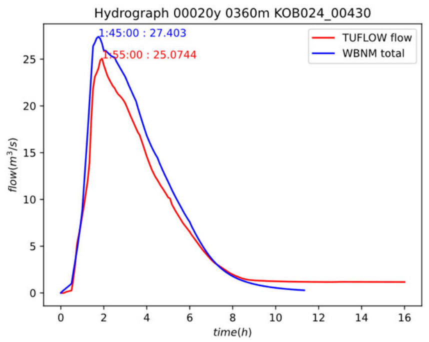
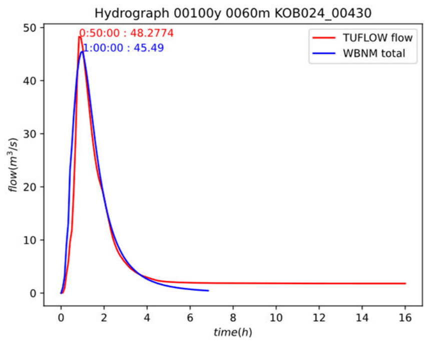
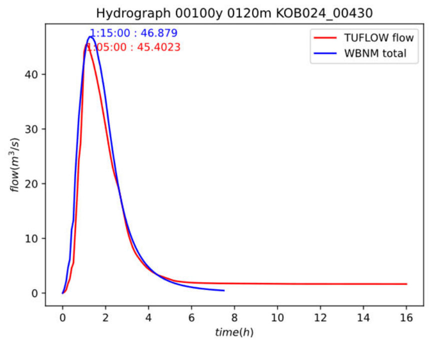
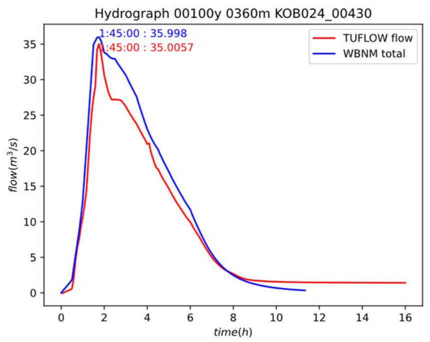
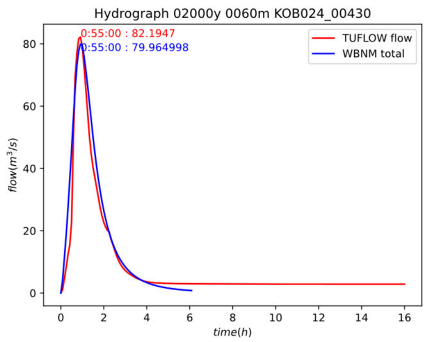


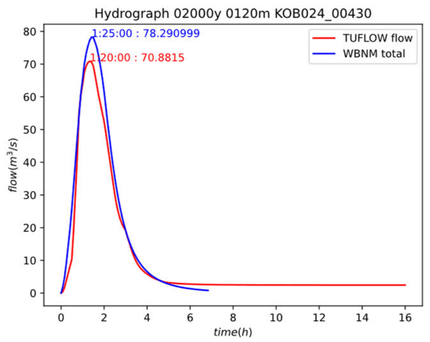



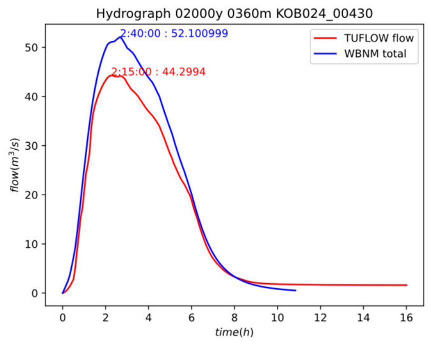



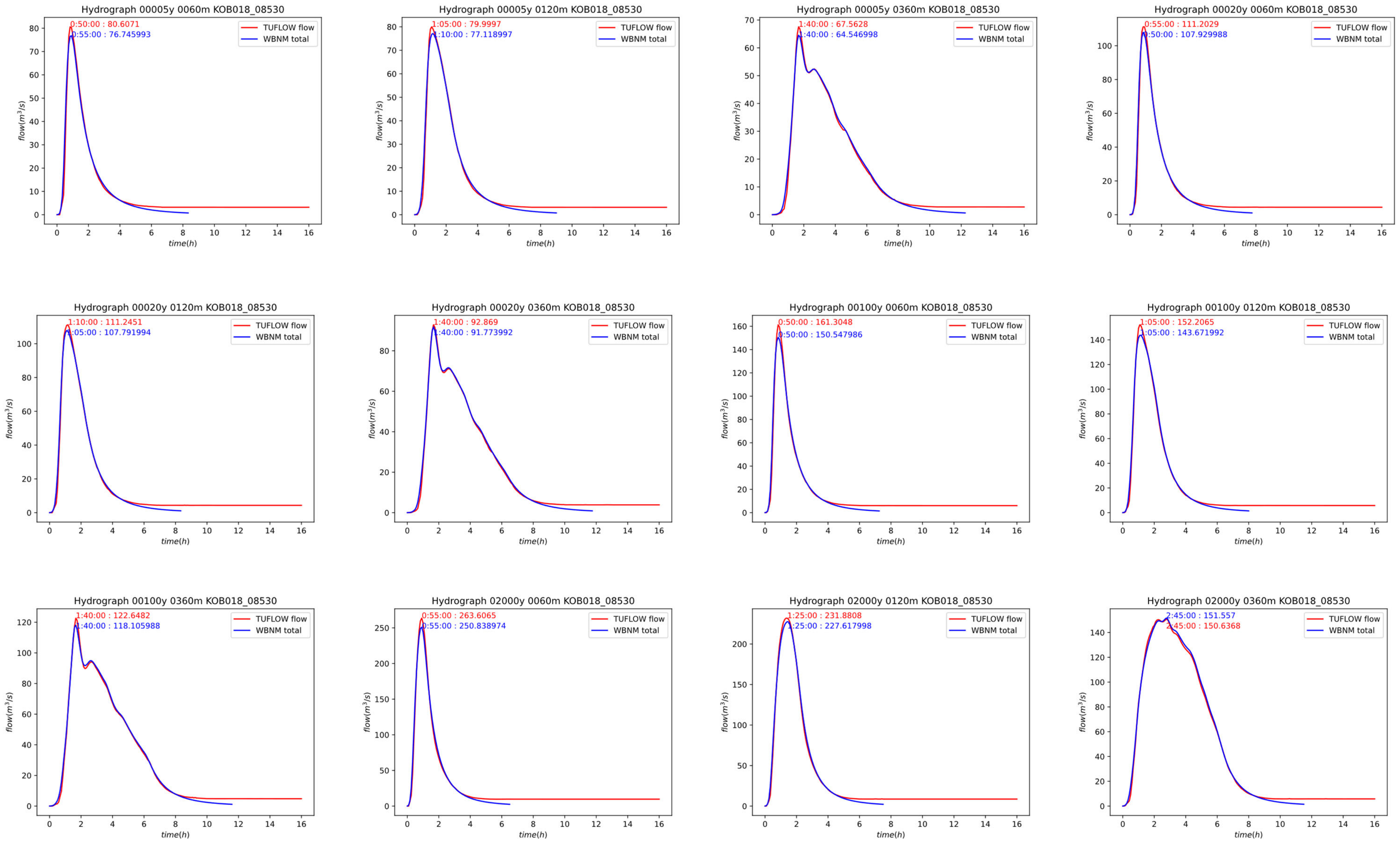



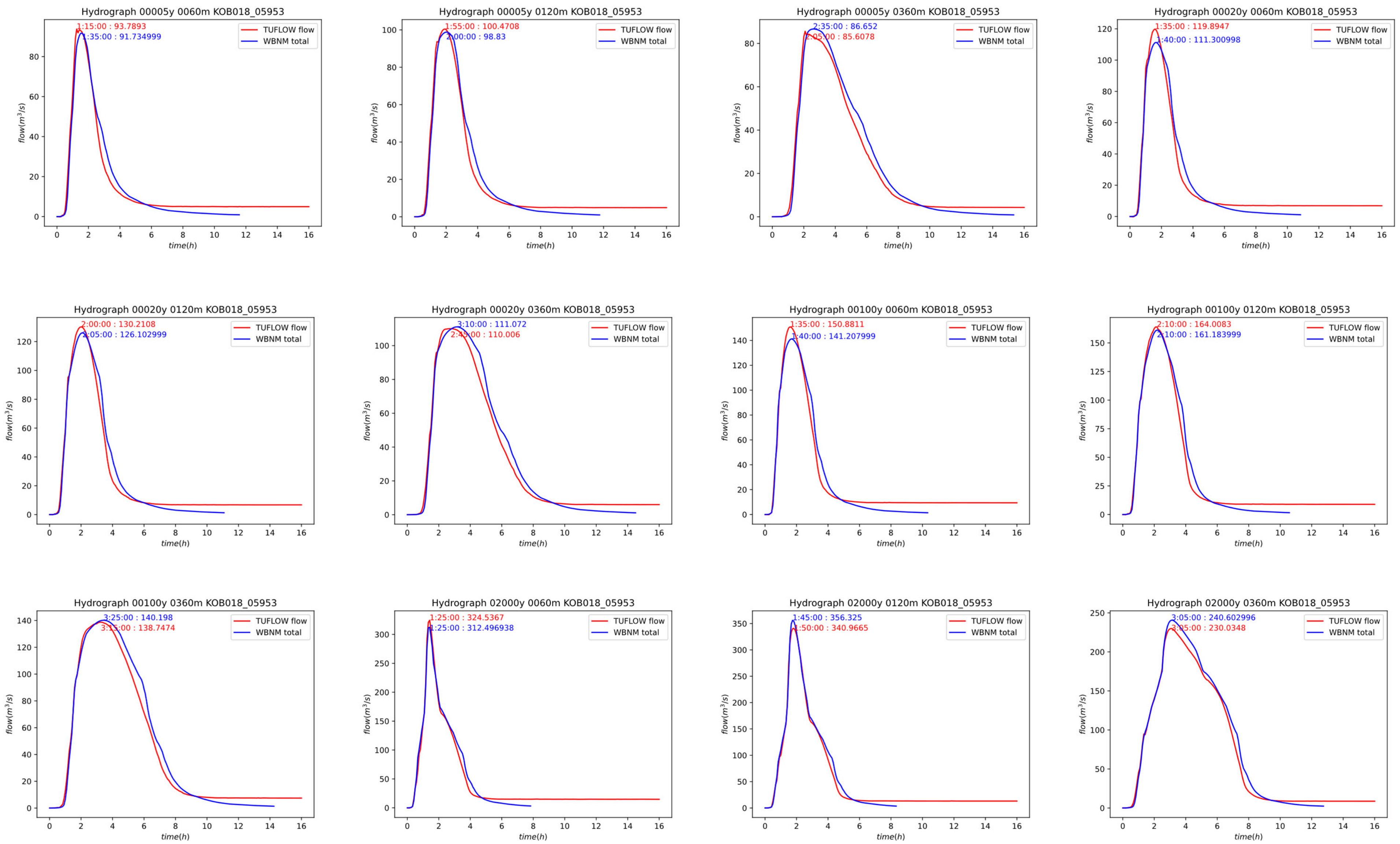



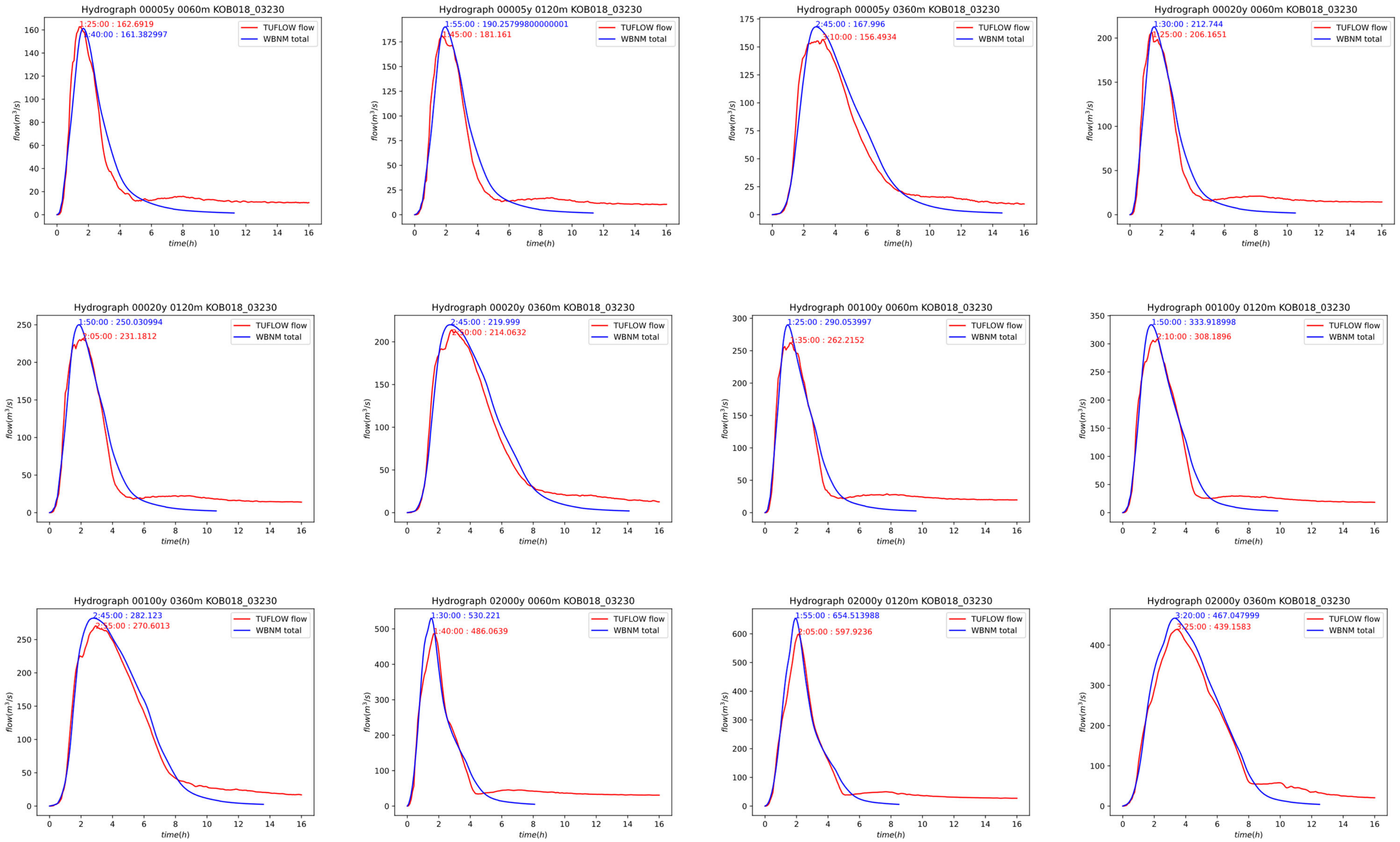

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.95 | 0.8 | 0.0 |
| 5-year 120-minute | 0.98 | 6.5 | 5.0 |
| 5-year 360-minute | 0.95 | 0.5 | 0.0 |
| 20-year 60-minute | 0.94 | -6.4 | 0.0 |
| 20-year 120-minute | 0.97 | 0.5 | 5.0 |
| 20-year 360-minute | 0.96 | 9.3 | -10.0 |
| 100-year 60-minute | 0.94 | -5.8 | 10.0 |
| 100-year 120-minute | 0.96 | 3.3 | 10.0 |
| 100-year 360-minute | 0.95 | 2.8 | 0.0 |
| 2000-year 60-minute | 0.95 | -2.7 | 0.0 |
| 2000-year 120-minute | 0.97 | 10.5 | 5.0 |
| 2000-year 360-minute | 0.95 | 17.6 | 25.0 |



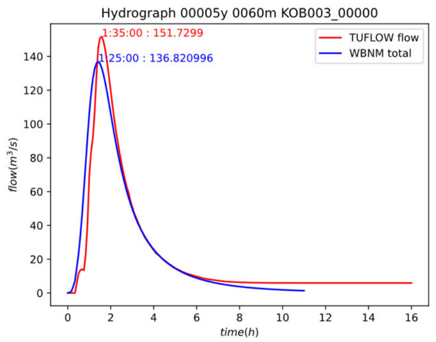

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.99 | -4.8 | 5.0 |
| 5-year 120-minute | 0.99 | -3.6 | 5.0 |
| 5-year 360-minute | 1.00 | -4.5 | 0.0 |
| 20-year 60-minute | 0.99 | -2.9 | -5.0 |
| 20-year 120-minute | 1.00 | -3.1 | -5.0 |
| 20-year 360-minute | 1.00 | -1.2 | 0.0 |
| 100-year 60-minute | 0.99 | -6.7 | 0.0 |
| 100-year 120-minute | 1.00 | -5.6 | 0.0 |
| 100-year 360-minute | 1.00 | -3.7 | 0.0 |
| 2000-year 60-minute | 0.99 | -4.8 | 0.0 |
| 2000-year 120-minute | 1.00 | -1.8 | 0.0 |
| 2000-year 360-minute | 1.00 | 0.6 | 0.0 |

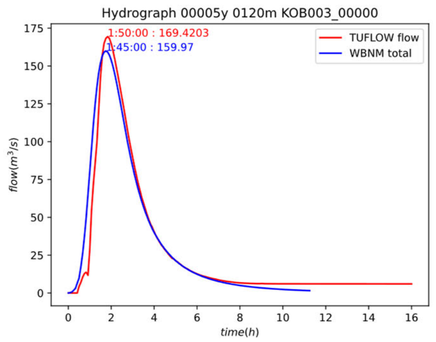


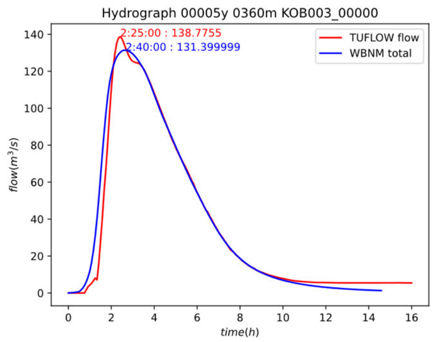

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.97 | -2.2 | 20.0 |
| 5-year 120-minute | 0.98 | -1.6 | 5.0 |
| 5-year 360-minute | 0.98 | 1.2 | 30.0 |
| 20-year 60-minute | 0.97 | -7.2 | 5.0 |
| 20-year 120-minute | 0.98 | -3.2 | 5.0 |
| 20-year 360-minute | 0.98 | 1.0 | 25.0 |
| 100-year 60-minute | 0.98 | -6.4 | 5.0 |
| 100-year 120-minute | 0.98 | -1.7 | 0.0 |
| 100-year 360-minute | 0.98 | 1.0 | 10.0 |
| 2000-year 60-minute | 0.99 | -3.7 | 0.0 |
| 2000-year 120-minute | 0.99 | 4.5 | -5.0 |
| 2000-year 360-minute | 0.99 | 4.6 | 0.0 |

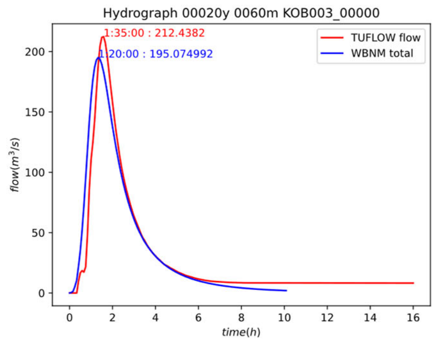



| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | -0.8 | 15.0 |
| 5-year 120-minute | 0.95 | 5.0 | 10.0 |
| 5-year 360-minute | 0.96 | 7.4 | -25.0 |
| 20-year 60-minute | 0.95 | 3.2 | 5.0 |
| 20-year 120-minute | 0.96 | 8.2 | -15.0 |
| 20-year 360-minute | 0.97 | 2.8 | -5.0 |
| 100-year 60-minute | 0.96 | 10.6 | -10.0 |
| 100-year 120-minute | 0.97 | 8.3 | -20.0 |
| 100-year 360-minute | 0.98 | 4.3 | -10.0 |
| 2000-year 60-minute | 0.96 | 9.1 | -10.0 |
| 2000-year 120-minute | 0.96 | 9.5 | -10.0 |
| 2000-year 360-minute | 0.97 | 6.4 | -5.0 |

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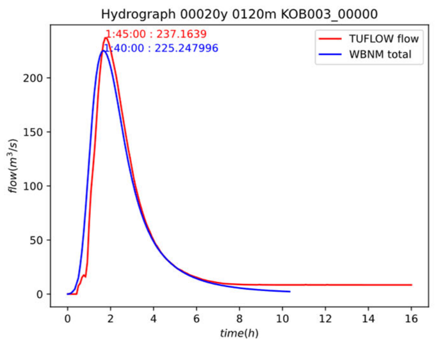
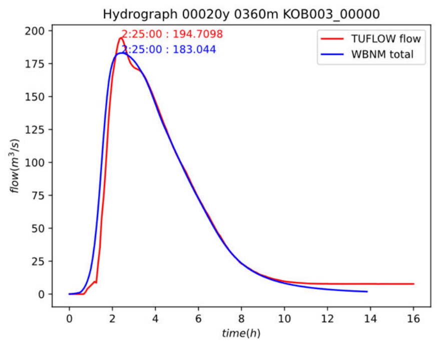
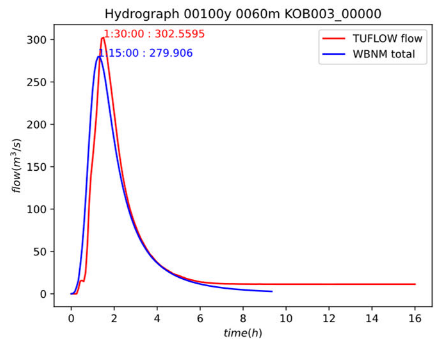
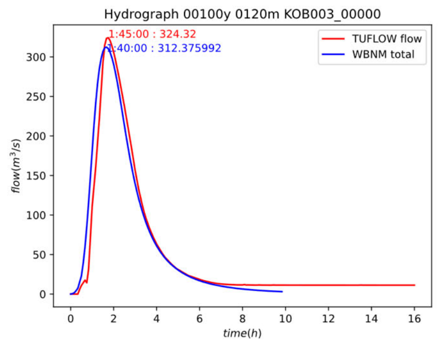
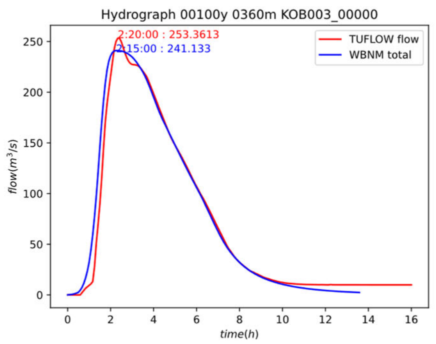
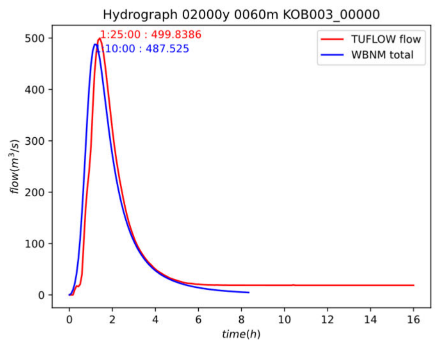


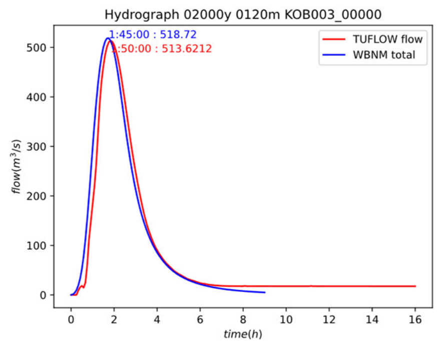



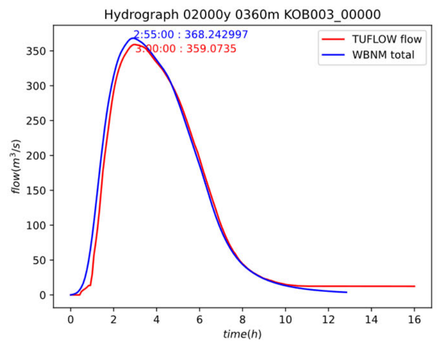



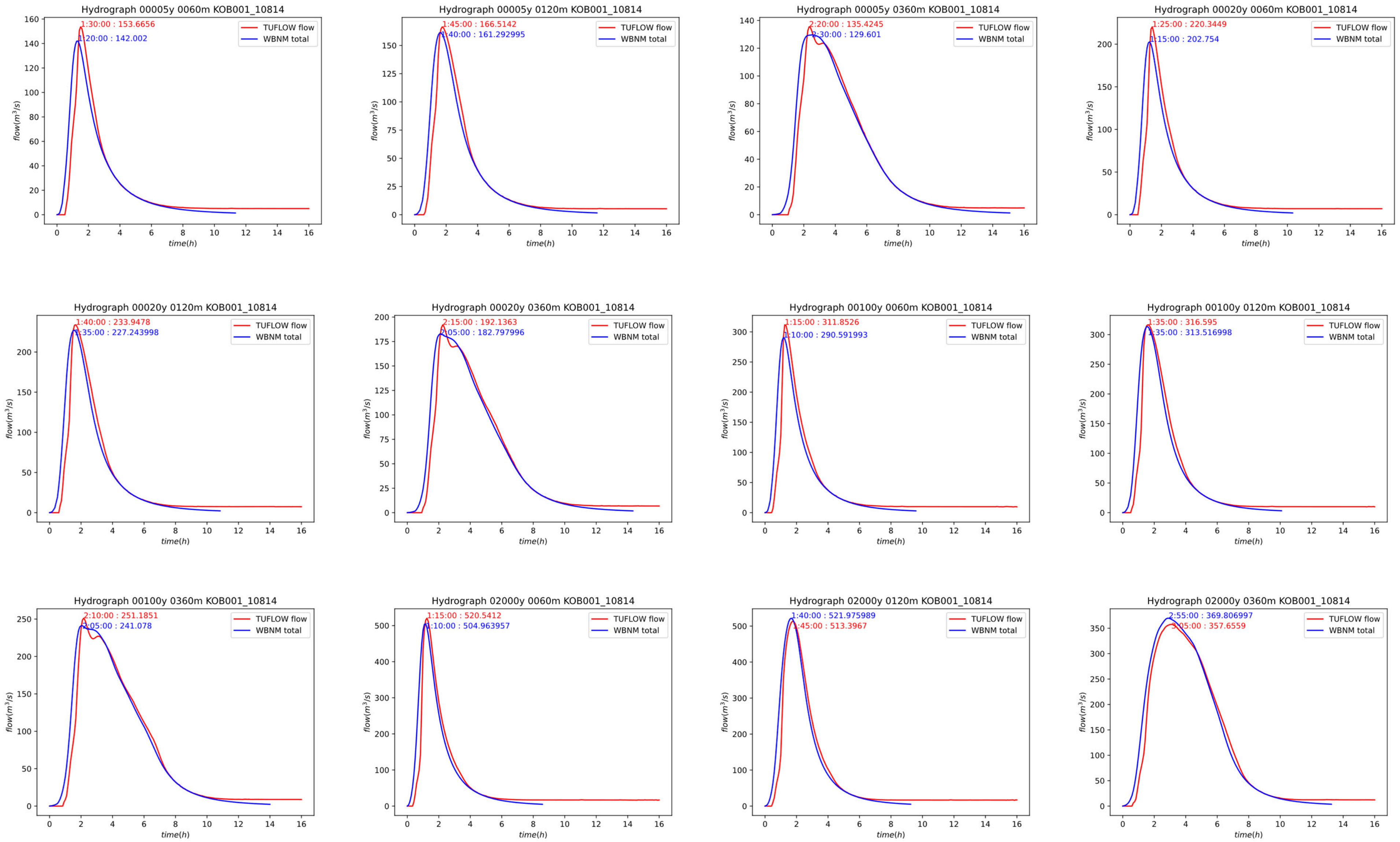



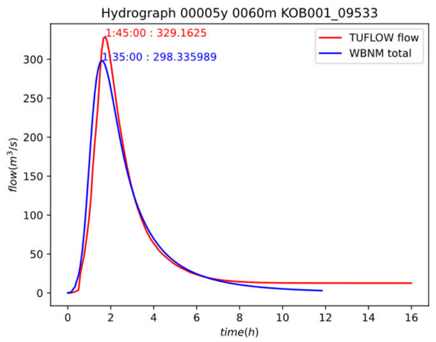



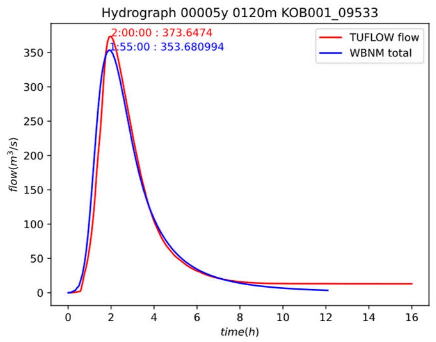



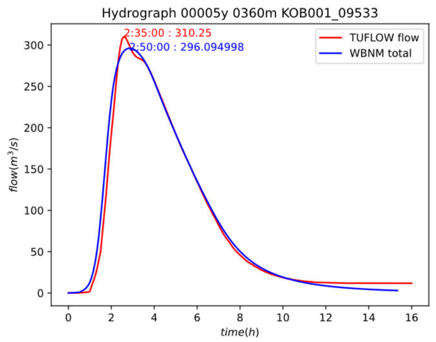

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.92 | -9.8 | -10.0 |
| 5-year 120-minute | 0.95 | -5.6 | -5.0 |
| 5-year 360-minute | 0.97 | -5.3 | 15.0 |
| 20-year 60-minute | 0.92 | -8.2 | -15.0 |
| 20-year 120-minute | 0.95 | -5.0 | -5.0 |
| 20-year 360-minute | 0.98 | -6.0 | 0.0 |
| 100-year 60-minute | 0.92 | -7.5 | -15.0 |
| 100-year 120-minute | 0.95 | -3.7 | -5.0 |
| 100-year 360-minute | 0.98 | -4.8 | -5.0 |
| 2000-year 60-minute | 0.92 | -2.5 | -15.0 |
| 2000-year 120-minute | 0.96 | 1.0 | -5.0 |
| 2000-year 360-minute | 0.99 | 2.6 | -5.0 |

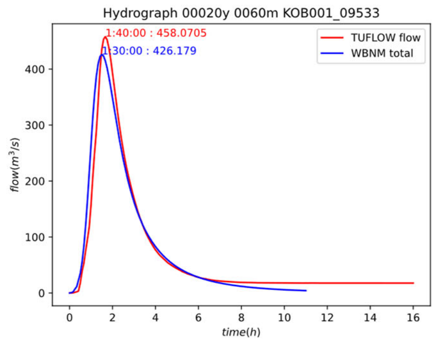


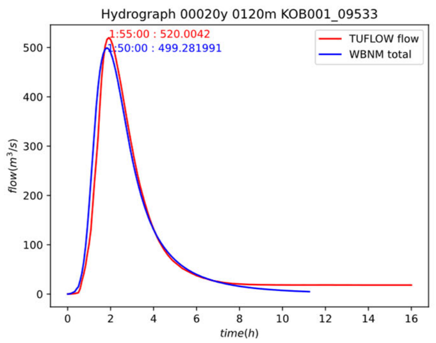

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.89 | -7.6 | -10.0 |
| 5-year 120-minute | 0.92 | -3.1 | -5.0 |
| 5-year 360-minute | 0.96 | -4.3 | 10.0 |
| 20-year 60-minute | 0.87 | -8.0 | -10.0 |
| 20-year 120-minute | 0.91 | -2.9 | -5.0 |
| 20-year 360-minute | 0.96 | -4.9 | -10.0 |
| 100-year 60-minute | 0.87 | -6.8 | -5.0 |
| 100-year 120-minute | 0.92 | -1.0 | 0.0 |
| 100-year 360-minute | 0.96 | -4.0 | -5.0 |
| 2000-year 60-minute | 0.90 | -3.0 | -5.0 |
| 2000-year 120-minute | 0.95 | 1.7 | -5.0 |
| 2000-year 360-minute | 0.98 | 3.4 | -10.0 |

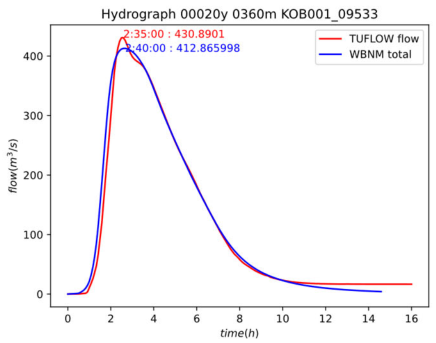


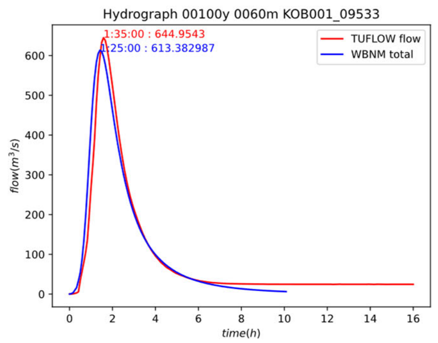



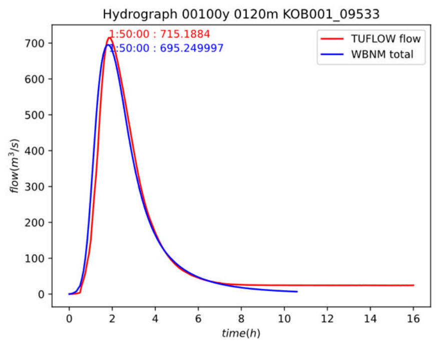



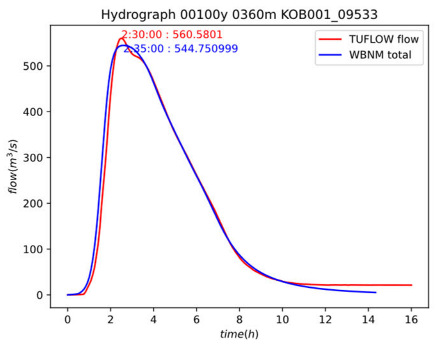



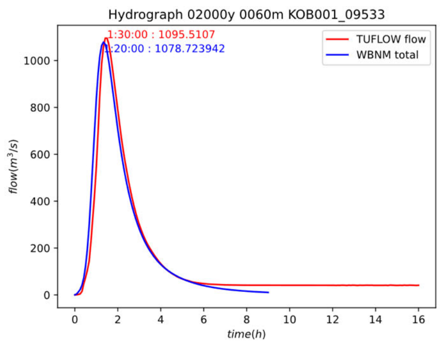



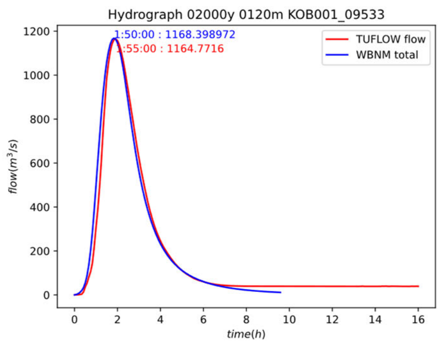



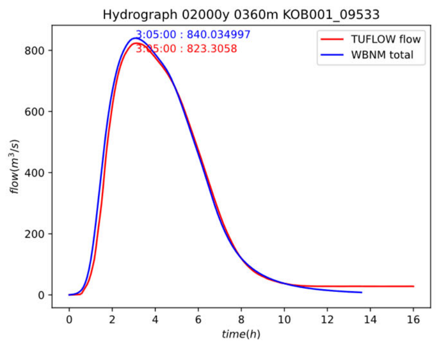



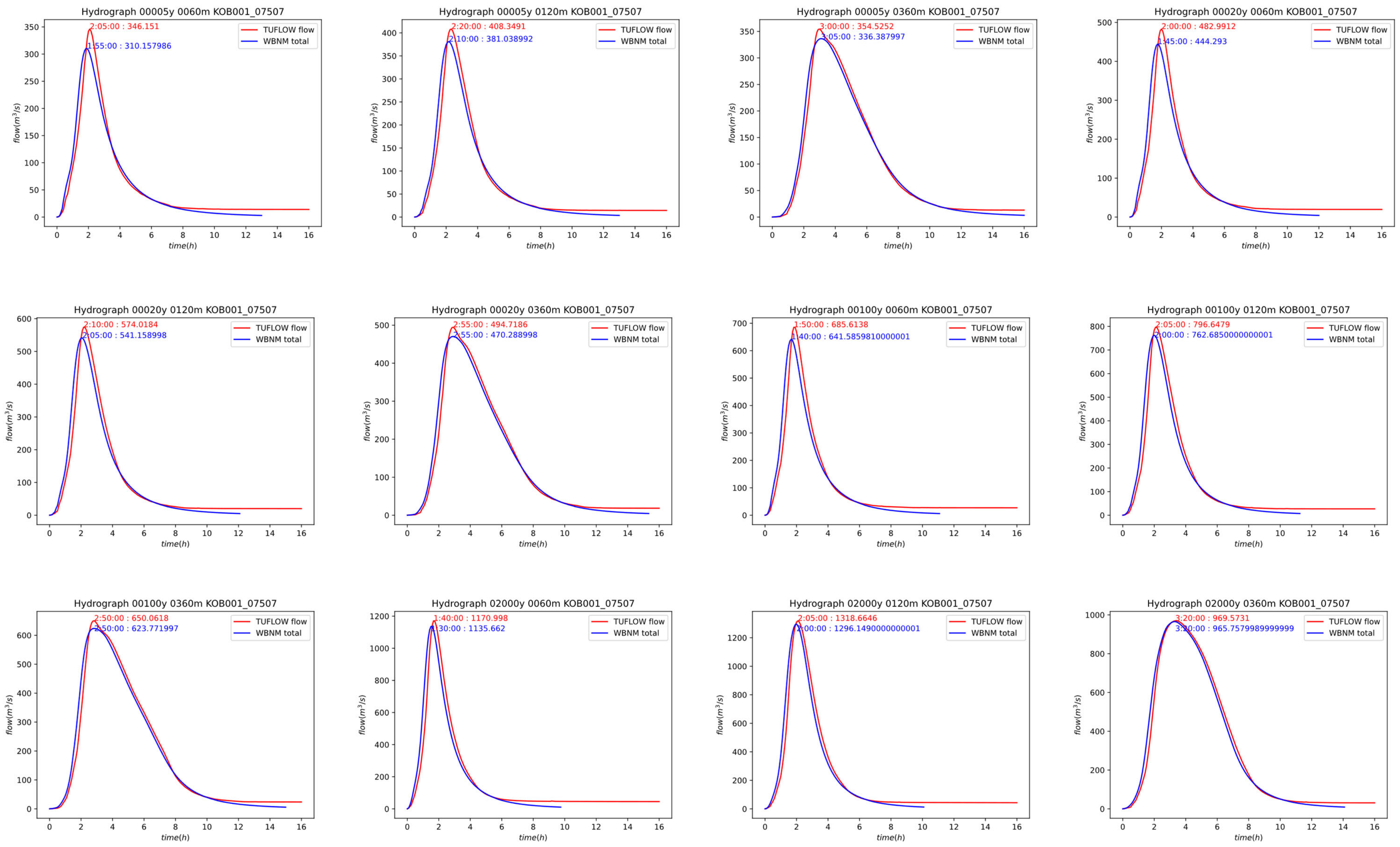



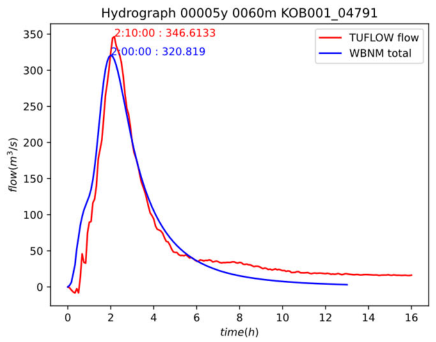



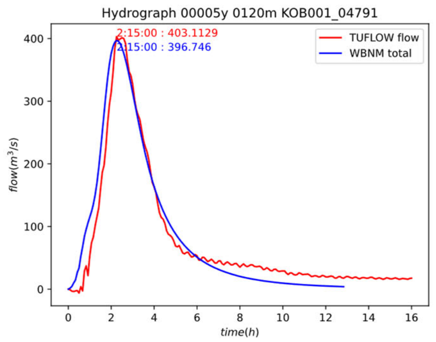



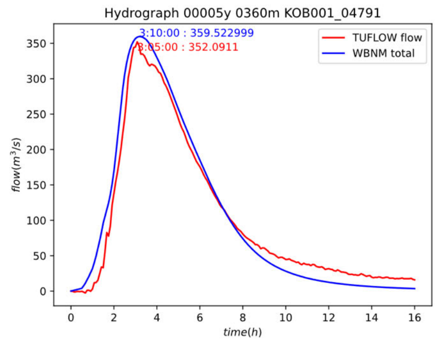

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | -9.4 | -10.0 |
| 5-year 120-minute | 0.98 | -5.3 | -5.0 |
| 5-year 360-minute | 0.99 | -4.6 | 15.0 |
| 20-year 60-minute | 0.96 | -7.0 | -10.0 |
| 20-year 120-minute | 0.97 | -4.0 | -5.0 |
| 20-year 360-minute | 0.99 | -4.2 | 5.0 |
| 100-year 60-minute | 0.96 | -4.9 | -10.0 |
| 100-year 120-minute | 0.97 | -2.8 | 0.0 |
| 100-year 360-minute | 0.99 | -2.8 | 5.0 |
| 2000-year 60-minute | 0.96 | -1.5 | -10.0 |
| 2000-year 120-minute | 0.98 | 0.3 | -5.0 |
| 2000-year 360-minute | 0.99 | 2.0 | 0.0 |

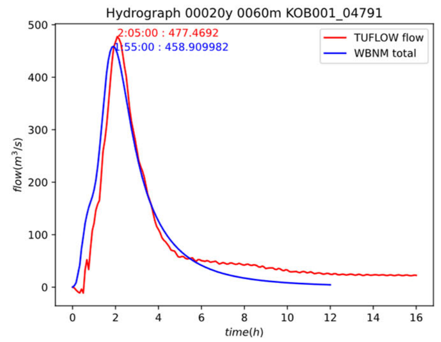


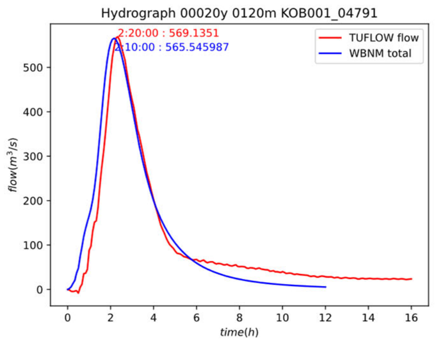

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.96 | -10.4 | -10.0 |
| 5-year 120-minute | 0.97 | -6.7 | -10.0 |
| 5-year 360-minute | 0.99 | -5.1 | 5.0 |
| 20-year 60-minute | 0.95 | -8.0 | -15.0 |
| 20-year 120-minute | 0.96 | -5.7 | -5.0 |
| 20-year 360-minute | 0.99 | -4.9 | 0.0 |
| 100-year 60-minute | 0.94 | -6.4 | -10.0 |
| 100-year 120-minute | 0.96 | -4.3 | -5.0 |
| 100-year 360-minute | 0.98 | -4.0 | 0.0 |
| 2000-year 60-minute | 0.95 | -3.0 | -10.0 |
| 2000-year 120-minute | 0.97 | -1.7 | -5.0 |
| 2000-year 360-minute | 0.99 | -0.4 | 0.0 |

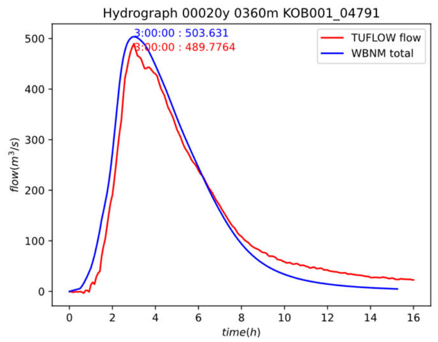


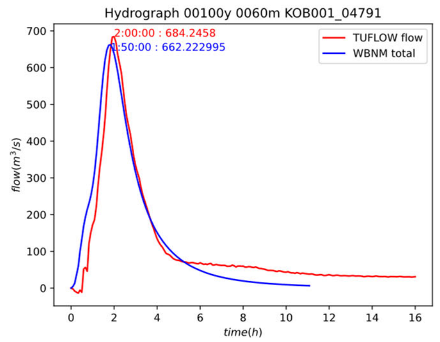



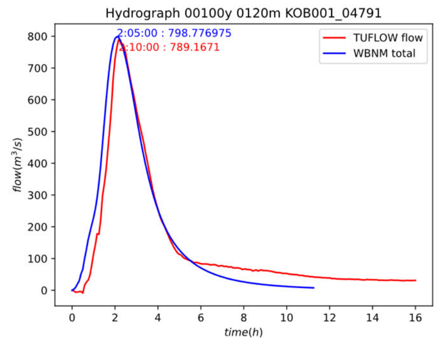



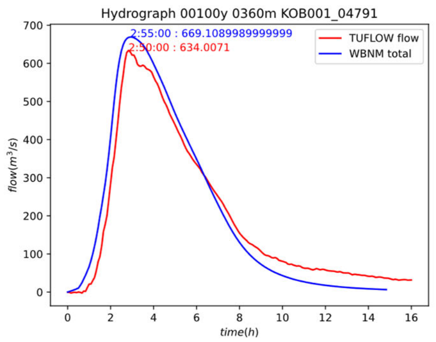



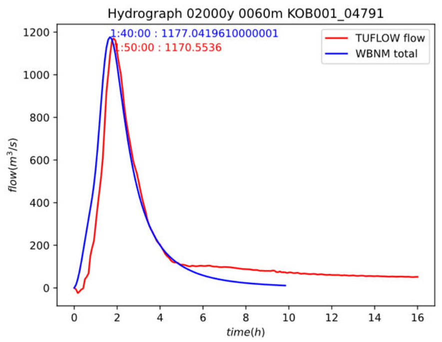



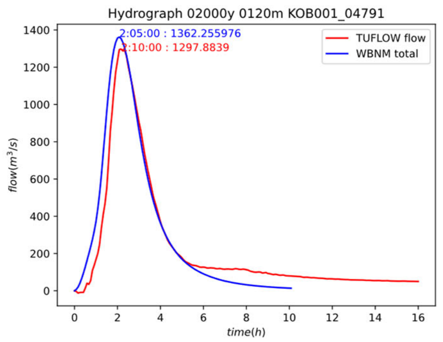



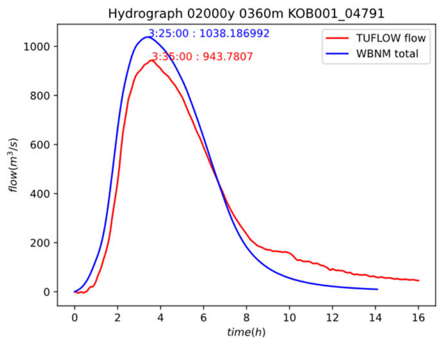



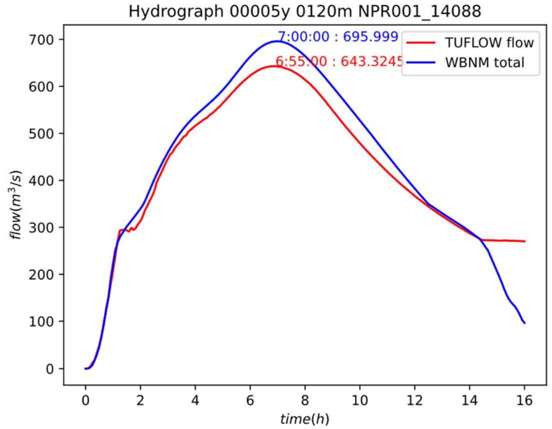



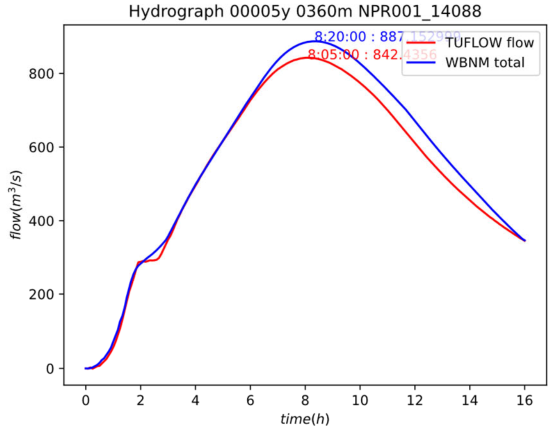



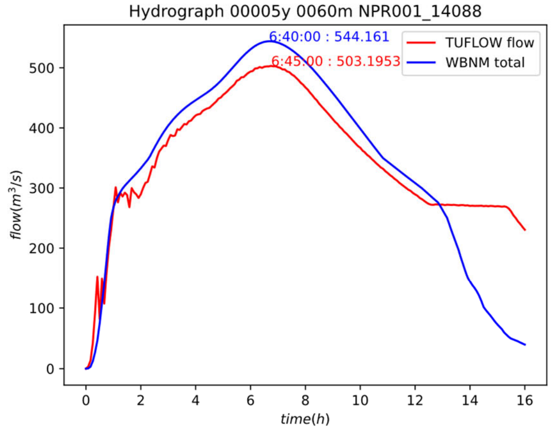



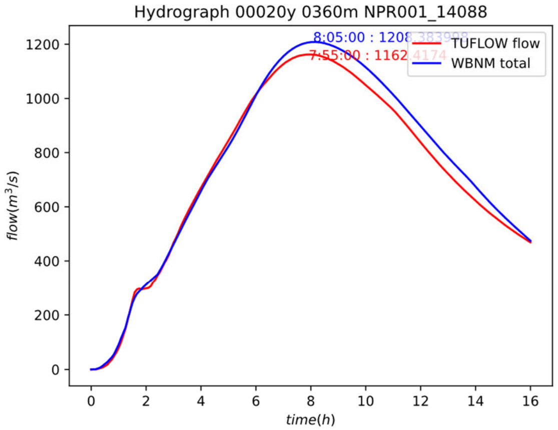



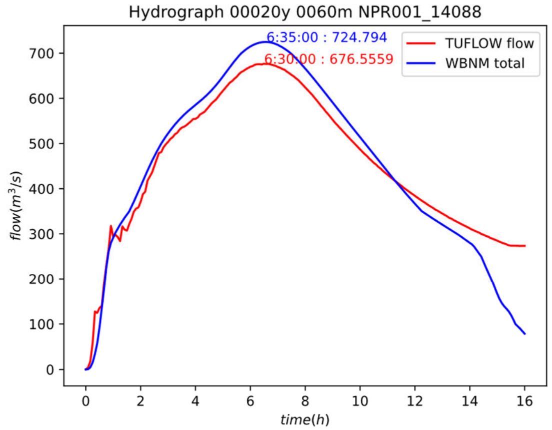

| ARI Event and Duration | Nash-Sutcliffe Efficiency | Peak Ratio (%) | Difference in Peak Timing (minutes) |
|---|---|---|---|
| 5-year 60-minute | 0.94 | -7.4 | -10.0 |
| 5-year 120-minute | 0.95 | -1.6 | 0.0 |
| 5-year 360-minute | 0.96 | 2.1 | 5.0 |
| 20-year 60-minute | 0.92 | -3.9 | -10.0 |
| 20-year 120-minute | 0.93 | -0.6 | -10.0 |
| 20-year 360-minute | 0.95 | 2.8 | 0.0 |
| 100-year 60-minute | 0.91 | -3.2 | -10.0 |
| 100-year 120-minute | 0.93 | 1.2 | -5.0 |
| 100-year 360-minute | 0.94 | 5.5 | 5.0 |
| 2000-year 60-minute | 0.90 | 0.6 | -10.0 |
| 2000-year 120-minute | 0.92 | 5.0 | -5.0 |
| 2000-year 360-minute | 0.93 | 10.0 | -10.0 |

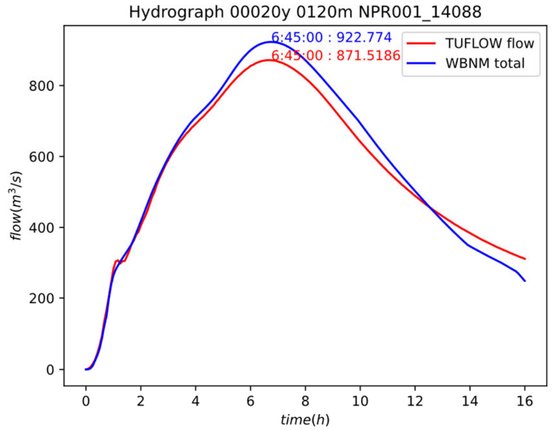

Hydrograph 00005y 0120m NPR001_14088
7:00:00 : 695.999
6:55:00 : 643.3245
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

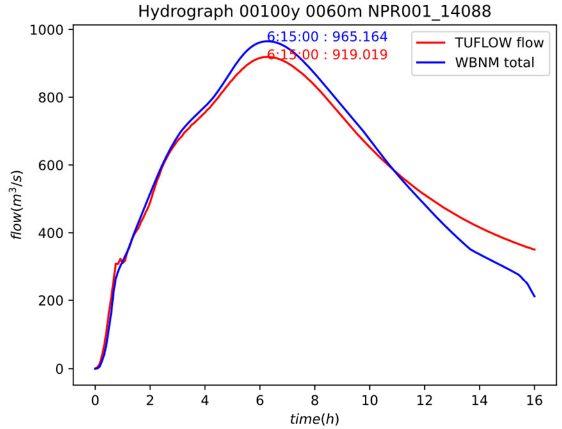

Hydrograph 00005y 0360m NPR001_14088
8:20:00 : 887
8:05:00 : 842
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

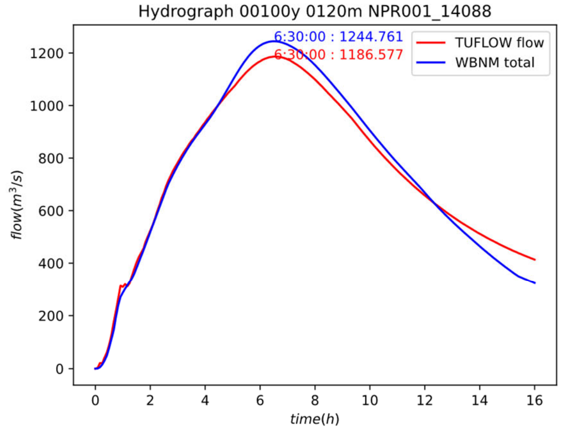

Hydrograph 00005y 0060m NPR001_14088
6:40:00 : 544.161
6:45:00 : 503.1953
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

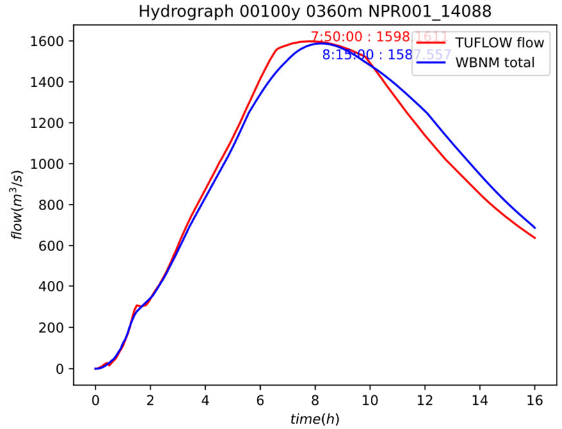

Hydrograph 00020y 0360m NPR001_14088
8:05:00 : 1208
7:55:00 : 1162
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

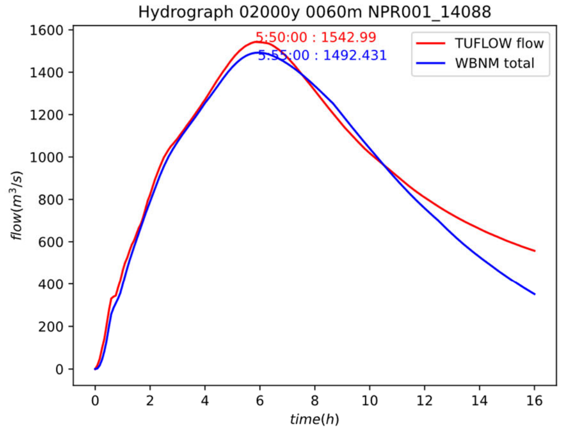

Hydrograph 00020y 0060m NPR001_14088
6:35:00 : 724.794
6:30:00 : 676.5559
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

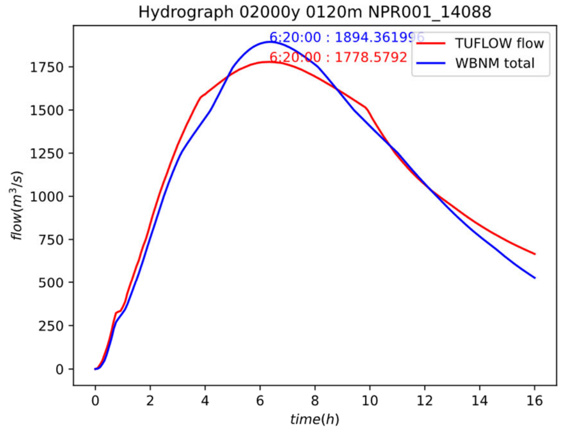

Hydrograph 00020y 0120m NPR001_14088
6:45:00 : 922.774
6:45:00 : 871.5186
TUFLOW flow
WBNM total
flow(m³/s)
time(h)

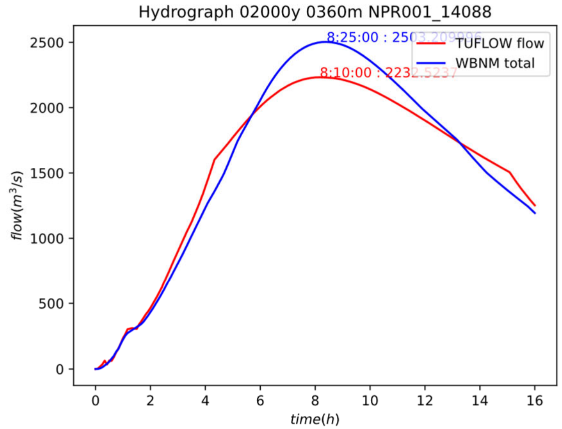

Hydrograph 00100y 0060m NPR001_14088
6:15:00 : 965.164
6:15:00 : 919.019
TUFLOW flow
WBNM total
flow(m3/s)
time(h)


Hydrograph 00100y 0120m NPR001_14088
6:30:00 : 1244.761
6:30:00 : 1186.577
TUFLOW flow
WBNM total
flow(m3/s)
time(h)

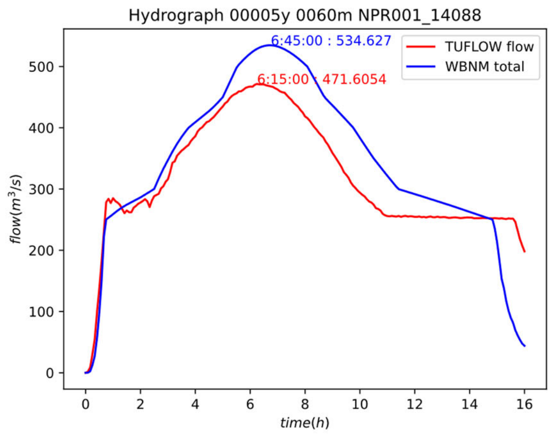

Hydrograph 00100y 0360m NPR001_14088
7:50:00 : 1598
8:15:00 : 158
TUFLOW flow
WBNM total
flow(m3/s)
time(h)

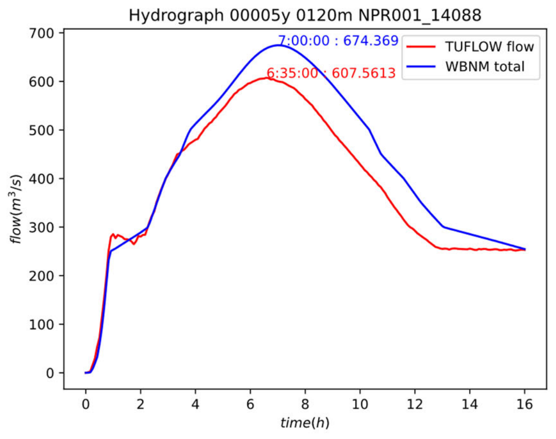

Hydrograph 02000y 0060m NPR001_14088
5:50:00 : 1542.99
5:55:00 : 1492.431
TUFLOW flow
WBNM total
flow(m3/s)
time(h)

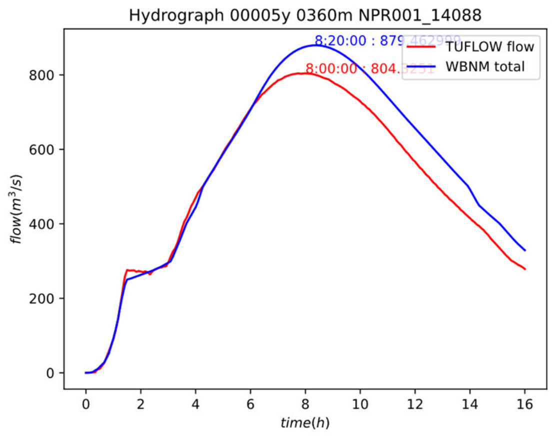

Hydrograph 02000y 0120m NPR001_14088
6:20:00 : 1894.36199
6:20:00 : 1778.5792
TUFLOW flow
WBNM total
flow(m3/s)
time(h)

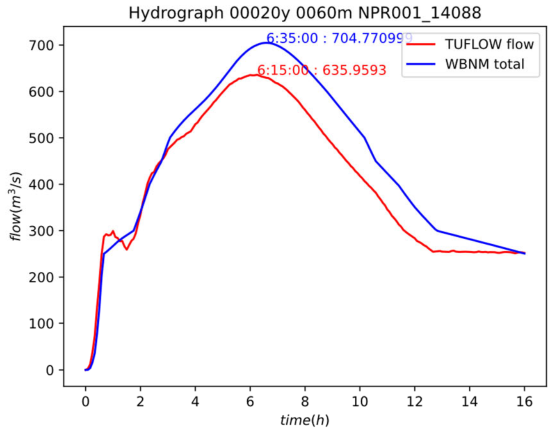

Hydrograph 02000y 0360m NPR001_14088
8:25:00 : 25
8:10:00 : 223
TUFLOW flow
WBNM total
flow(m3/s)
time(h)

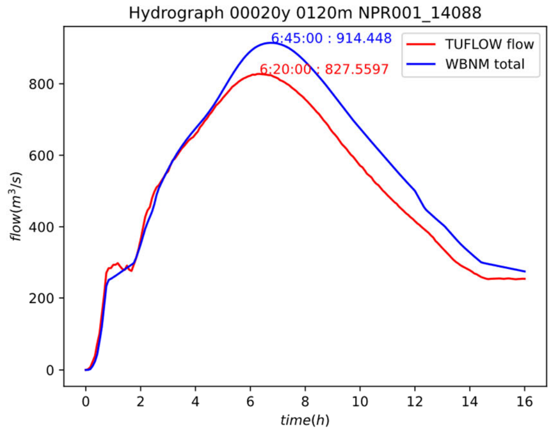
## Revision 9 (Future Conditions)

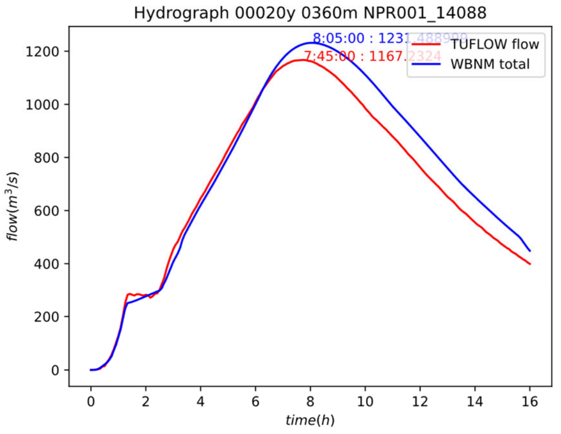


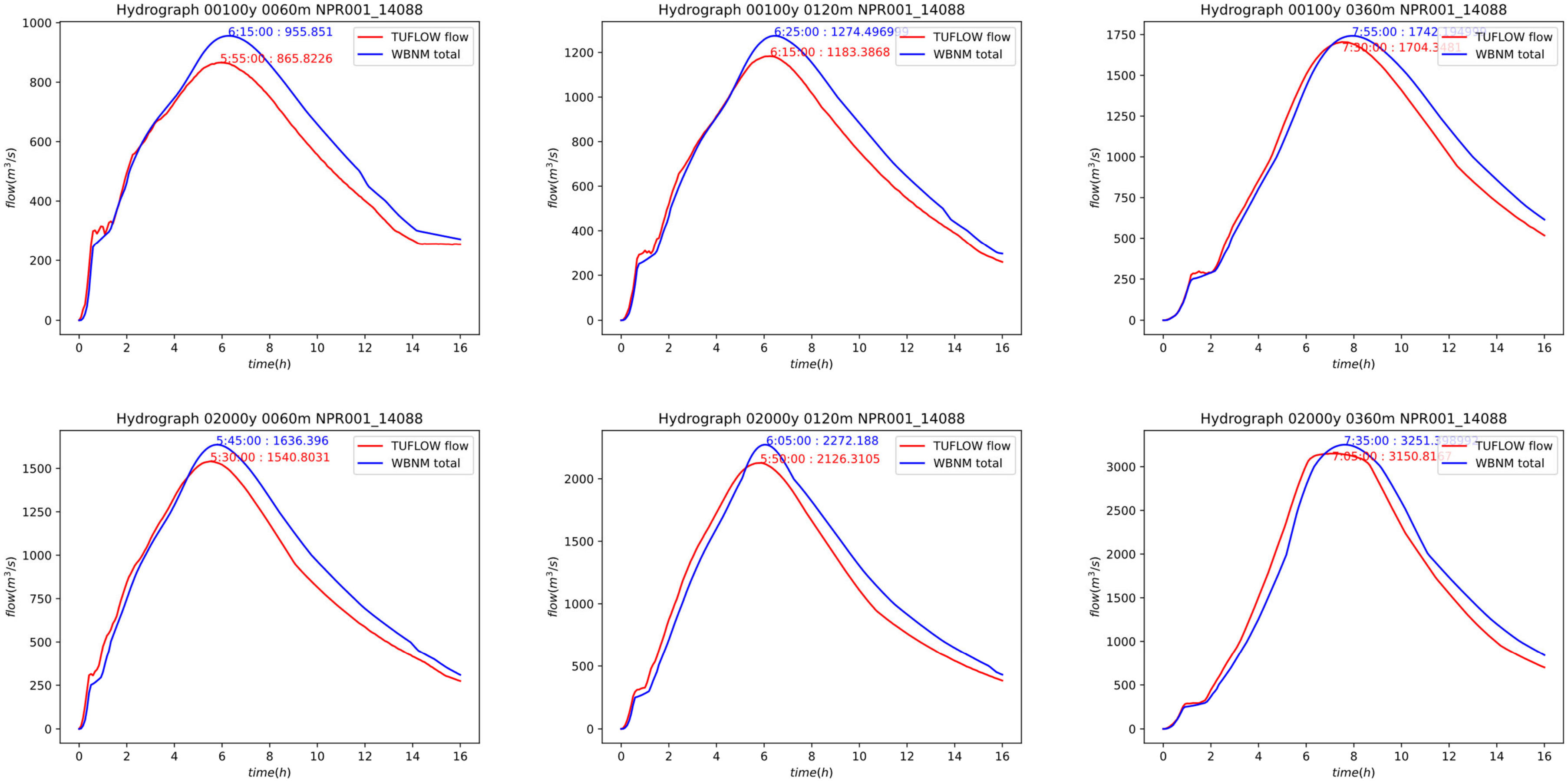




Hydrograph 00100y 0060m NPR001_14088
6:15:00 : 955.851
5:55:00 : 865.8226
Hydrograph 00100y 0120m NPR001_14088
6:25:00 : 1274.496999
6:15:00 : 1183.3868
Hydrograph 00100y 0360m NPR001_14088
7:55:00 : 1742.194999
7:30:00 : 1704.3481
Hydrograph 02000y 0060m NPR001_14088
5:45:00 : 1636.396
5:30:00 : 1540.8031
Hydrograph 02000y 0120m NPR001_14088
6:05:00 : 2272.188
5:50:00 : 2126.3105
Hydrograph 02000y 0360m NPR001_14088
7:35:00 : 3251.398997
7:05:00 : 3150.8167
TUFLOW flow
WBNM total
flow($m^3$/s)
time(h)

# Annex E Blockage Factors

Table E.1. Modelled Culvert Blockage

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 001_00704a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_00704b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_01661 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_04181 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_04252b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_05600 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_05730 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213e | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213f | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213g | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_06213h | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 001_06213i | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_09533b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544e | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_11544f | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_12524a | 25 | 0 | 0.5 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_12524b | 25 | 0 | 0.5 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_14066a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_14066b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_36264a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_36264b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_36264c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_37410 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_38235a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_38235b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_52484a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 001_52484b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_52484c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_52484d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_52484e | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_56115a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_56115b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 001_57247a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 001_57247b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 002_00010a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 002_00010b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 002_00010c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 002_00010d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_01073 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_01290 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_02145a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_02145b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_03083 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 003_03199 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 003_03743b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 004_00145a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 004_00145b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 004_00295 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 005_00000 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 006_01549 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 007_00000a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 007_00000b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 007_00000c | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 007_00000d | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 007_00973 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 007_02637a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 007_02637b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 008_00298 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 009_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 009_00557 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 010_00204b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 010_01237 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 010_02189 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 010_03025a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 010_03025b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 010_03617 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 010_04276 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 010_04603a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 010_04603b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 011_01150 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 011_01584 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00329 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00488 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00652 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 012_00735a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00735b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_00754 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 012_02652 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 013_00000a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 013_00000b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 013_00887 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 013_01237b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 014_00000 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 014_01094 | 25 | 0 | 0.5 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 015_00267a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 015_00267b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 015_00411a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 015_00411b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 016_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 016_00134 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 016_00201 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 017_00000b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 017_00733 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 017_01032 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 018_00140 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 018_05953a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 018_05953b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 018_05953c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 019_00216 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 019_00343 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 020_00251 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 020_00845a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 020_00845b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 020_00845c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 021_00069 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 022_00204 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 022_00539 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 023_00221 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 024_00069a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 024_00069b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 024_00430 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 024_01264a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 024_01264b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 024_01917a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 024_01917b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 024_01917c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 025_00000a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 025_00429 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 026_00770 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 026_01144 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 026_01966a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 026_01966b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 027_00408 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 028_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 028_00748 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 028_01263 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 028_02882 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 029_00039 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 029_00120a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 029_00120b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 030_00000a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 030_00000b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 030_01159b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 030_02379 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 031_00312a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 031_00312b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 032_00957 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 033_01639 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 034_00827a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 034_00827b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 034_00827c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 035_01732 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 037_01125 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_00000 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 040_01186a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_01186b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_01186c | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_01186d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_01186e | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 040_01186f | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 042_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 044_01172a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 044_01172b | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 044_01172c | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 044_01172d | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 044_01172e | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 044_01172f | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 049_00054 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 056_00000a | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 056_00000b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 056_01297a | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 056_01297b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 058_00370 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 059_00680 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 062_00265 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 062_00373 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 064_00000b | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 064_01040 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 065_00217 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 072_00151 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 072_00321 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 074_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 075_00484 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 076_00172 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 080_00166 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| 085_00259 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5%AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Culvert ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 086_00000 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 086_00275 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |

Table E.2. Modelled Trunk Drainage Pipe Blockage

| | Less than 5% AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| 809783 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 824903 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 905859 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 905860 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| 1134374 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134375 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134376 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134377 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134378 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134379 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134380 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134381 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134382 | 0 | 0 | 0.5 | 15 | 0 | 0.5 | 25 | 0 | 0.5 |
| 1134385 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN041359 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN052590 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN054255 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| SWN058336 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5% AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| SWN093522 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN093523 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN093524 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN096514 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113785 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113786 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113787 | 25 | 0 | 0.5 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113788 | 25 | 0 | 0.5 | 50 | 0 | 0.5 | 100 | 0 | 0.5 |
| SWN113789 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113790 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113791 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113792 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113793 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN113794 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN201364 | 25 | 0 | 0.5 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN201365 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN201366 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN201367 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302184 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

| | Less than 5% AEP Events | | | 5% to 0.5% AEP Events | | | Greater than 0.5% AEP Events | | |
|---|---|---|---|---|---|---|---|---|---|
| Pipe ID | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss | Blockage (%) | Form Loss | Entry Loss |
| SWN302185 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302189 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302190 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302191 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302192 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |
| SWN302193 | 0 | 0.63 | 1 | 0 | 4.83 | 1 | 100 | 0 | 0.5 |

Table E.3. Modelled Bridge Blockage

| | Less than 5% AEP Events | 5% to 0.5% AEP Events | Greater than 0.5% AEP Events |
|---|---|---|---|
| Bridge ID | L1 Blockage (%) | L1 Blockage (%) | L1 Blockage (%) |
| KOB_01_09533 | 0 | 0 | 10 |
| NPR_01_32878 | 0 | 0 | 10 |
| NPR_01_41506 | 0 | 0 | 10 |
| NPR_01_49127 | 0 | 0 | 10 |
| NPR_33_00067 | 0 | 0 | 10 |
| TER_01_04450 | 0 | 0 | 10 |
| TER_01_05833 | 0 | 0 | 10 |

# Annex F Upper Pine River Design Event Hydrology Modelling and Results

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# Draft Technical Note

| | | | |
|---|---|---|---|
| Project | A11567 – RFD 2021 Major Update | | |
| From: | Blair Filer | | |
| Date: | 15/07/2023 | To: | Hester van Zijl (MBRC) |
| Doc Ref: | T.A11567.019 | | |
| Subject: | Upper Pine River 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 Upper Pine River. 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 storms 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 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.
- 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 ‘Upper Pine River 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 Upper Pine River 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 tabulates 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 Upper Pine River, 8 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 | KOB032_00957, TER010_02189 |
| ARFb | $1km^2$ to $5km^2$ | $2.5km^2$ | Point | NPR056_01297, TER012_00000, KOB024_00430 |
| ARFc | $5km^2$ to $15km^2$ | $10km^2$ | Point | TER001_05833, KOB018_05953, NPR011_DUM01, LAC001_11829, NPR001_DUM03 |
| ARFd | $15km^2$ to $35km^2$ | $25km^2$ | Point | TER001_04450, KOB018_02518, TER001_01661, NPR001_49127 |
| ARFe | $35km^2$ to $75km^2$ | $50km^2$ | Point | LAC001_11544, KOB001_10541, KOB001_09533, KOB001_DUM01, LAC001_05600, LAC001_04181 |
| ARFf | $75km^2$ to $140km^2$ | $100km^2$ | Areal $100km^2$ | NPR001_DUM02, NPR001_41506, NPR001_40819 |
| ARFg | $140km^2$ to $210km^2$ | $175km^2$ | Areal $200km^2$ | NPR001_38235, NPR001_34279, NPR001_31927, NPR001_DUM01 |
| ARFh | $210km^2$ to $300km^2$ | $250km^2$ | Areal $200km^2$ | |
| ARFi | $300km^2$ to $475km^2$ | $400km^2$ | Areal $500km^2$ | NPR001_13848 |
| ARFj | $475km^2$ to $700km^2$ | $575km^2$ | Areal $500km^2$ | |
| ARFk | $700km^2$ to $1000km^2$ | $850km^2$ | Areal $1000km^2$ | |

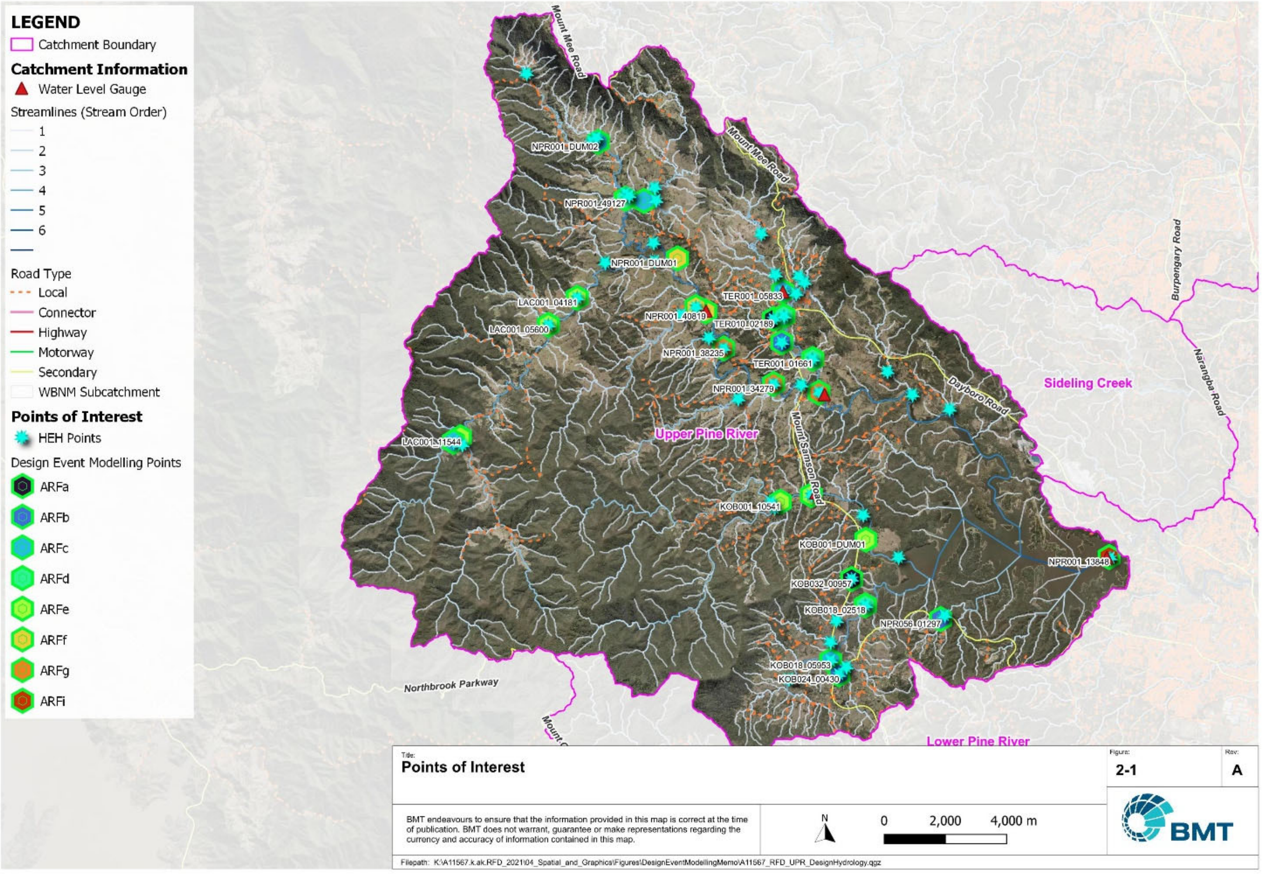



Figure 2.1 Points of Interest

# 3 Design Event Modelling Inputs

## 3.1 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 'Upper Pine River HEH Modelling and Results' Technical Note.

Two variants of the model with different fraction impervious data were used for the design event modelling. In addition, each variant had a different outflow rating curve from North Pine Dam. These variations 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.

  SEQWater's revision 11 rating curve was applied to the outflow of the North Pine Dam.

- 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.

  SEQWater's revision 9 rating curve was applied to the outflow of the North Pine Dam.

## 3.2 Parameters

Specific details with regard to setting up the design event hydrology model are summarised in **Error! Reference source not found.**. The parameters were setup within StormInjector version 1.3.7_HL and the simulated hydrologic models used 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:<br>AEP events– 20%, 10% 5%, 2%, 1%, 0.1%, and 0.05%<br>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:<br>1. Apply median pre-burst depth values distributed using the 1hr GSDM pattern for storm burst durations of 60-minutes (1-hours) and less.<br>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).<br>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). |

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

| Parameter | Comment |
| --- | --- |
| | 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 North Pine Dam. |
| 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:<br>• No factoring was applied for the existing conditions.<br>• 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.<br>Embedded bursts within temporal patterns were smoothed using the StormInjector software. Where smoothing exceeded 40% these simulations were removed from the critical event selection as recommended in ARUP (2021)[2]. |
| 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 Event at each Design Event Modelling point - 20% AEP

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 180 | 1 | 3.1 |
| TER010_02189 | ARFa | 180 | 9 | 13.9 |
| NPR056_01297 | ARFb | 180 | 1 | 9.9 |
| TER012_00000 | ARFb | 180 | 6 | 24.2 |
| KOB024_00430 | ARFb | 180 | 3 | 20.3 |
| TER001_05833 | ARFc | 270 | 1 | 93.7 |
| KOB018_05953 | ARFc | 270 | 7 | 87.2 |
| NPR011_DUM01 | ARFc | 180 | 3 | 102.7 |
| LAC001_11829 | ARFc | 270 | 5 | 85.9 |
| NPR001_DUM03 | ARFc | 180 | 6 | 105.3 |
| TER001_04450 | ARFd | 270 | 7 | 143.5 |
| KOB018_02518 | ARFd | 270 | 7 | 155.9 |
| TER001_01661 | ARFd | 270 | 7 | 169.1 |
| NPR001_49127 | ARFd | 270 | 7 | 218.6 |
| LAC001_11544 | ARFe | 270 | 5 | 239.1 |
| KOB001_10541 | ARFe | 270 | 7 | 263.9 |
| KOB001_09533 | ARFe | 270 | 7 | 290.7 |
| KOB001_DUM01 | ARFe | 270 | 7 | 323.7 |
| LAC001_05600 | ARFe | 270 | 7 | 354.1 |
| LAC001_04181 | ARFe | 270 | 7 | 368.9 |

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| NPR001_DUM02 | ARFf | 270 | 7 | 603.3 |
| NPR001_41506 | ARFf | 270 | 7 | 608.0 |
| NPR001_40819 | ARFf | 540 | 7 | 670.9 |
| NPR001_38235 | ARFg | 540 | 7 | 656.4 |
| NPR001_34279 | ARFg | 360 | 5 | 658.2 |
| NPR001_31927 | ARFg | 360 | 5 | 796.8 |
| NPR001_DUM01 | ARFg | 360 | 5 | 828.4 |
| NPR001_13848 | ARFi | 1080 | 17 | 899.1 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 180 | 4 | 3.5 |
| TER010_02189 | ARFa | 180 | 1 | 17.2 |
| NPR056_01297 | ARFb | 180 | 8 | 11.5 |
| TER012_00000 | ARFb | 180 | 4 | 31.4 |
| KOB024_00430 | ARFb | 180 | 4 | 26.0 |
| TER001_05833 | ARFc | 180 | 4 | 130.0 |
| KOB018_05953 | ARFc | 180 | 8 | 102.7 |
| NPR011_DUM01 | ARFc | 180 | 4 | 137.8 |
| LAC001_11829 | ARFc | 180 | 8 | 118.1 |
| NPR001_DUM03 | ARFc | 180 | 6 | 139.7 |
| TER001_04450 | ARFd | 180 | 4 | 194.0 |
| KOB018_02518 | ARFd | 180 | 8 | 198.3 |
| TER001_01661 | ARFd | 180 | 4 | 228.2 |
| NPR001_49127 | ARFd | 180 | 4 | 294.9 |
| LAC001_11544 | ARFe | 180 | 8 | 322.0 |
| KOB001_10541 | ARFe | 180 | 4 | 335.1 |
| KOB001_09533 | ARFe | 180 | 4 | 373.8 |
| KOB001_DUM01 | ARFe | 180 | 4 | 426.2 |
| LAC001_05600 | ARFe | 180 | 4 | 470.1 |
| LAC001_04181 | ARFe | 180 | 4 | 492.1 |
| NPR001_DUM02 | ARFf | 180 | 4 | 798.1 |
| NPR001_41506 | ARFf | 180 | 4 | 801.9 |
| NPR001_40819 | ARFf | 360 | 7 | 877.4 |
| NPR001_38235 | ARFg | 360 | 7 | 856.3 |
| NPR001_34279 | ARFg | 360 | 9 | 909.6 |
| NPR001_31927 | ARFg | 360 | 10 | 1104.0 |
| NPR001_DUM01 | ARFg | 360 | 10 | 1132.1 |
| NPR001_13848 | ARFi | 1080 | 19 | 1141.3 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 180 | 4 | 4.0 |
| TER010_02189 | ARFa | 180 | 4 | 21.8 |
| NPR056_01297 | ARFb | 180 | 4 | 12.6 |
| TER012_00000 | ARFb | 180 | 6 | 38.4 |
| KOB024_00430 | ARFb | 180 | 8 | 30.6 |
| TER001_05833 | ARFc | 180 | 8 | 160.1 |
| KOB018_05953 | ARFc | 180 | 4 | 114.8 |
| NPR011_DUM01 | ARFc | 180 | 8 | 171.0 |
| LAC001_11829 | ARFc | 180 | 6 | 142.6 |
| NPR001_DUM03 | ARFc | 180 | 6 | 168.6 |
| TER001_04450 | ARFd | 180 | 8 | 240.3 |
| KOB018_02518 | ARFd | 180 | 8 | 225.5 |
| TER001_01661 | ARFd | 180 | 4 | 283.1 |
| NPR001_49127 | ARFd | 180 | 8 | 364.5 |
| LAC001_11544 | ARFe | 180 | 8 | 386.6 |
| KOB001_10541 | ARFe | 180 | 8 | 412.3 |
| KOB001_09533 | ARFe | 180 | 8 | 457.8 |
| KOB001_DUM01 | ARFe | 180 | 8 | 521.0 |
| LAC001_05600 | ARFe | 180 | 8 | 574.4 |
| LAC001_04181 | ARFe | 180 | 8 | 601.3 |
| NPR001_DUM02 | ARFf | 180 | 8 | 986.7 |
| NPR001_41506 | ARFf | 180 | 8 | 992.7 |
| NPR001_40819 | ARFf | 180 | 8 | 1057.2 |
| NPR001_38235 | ARFg | 360 | 9 | 1052.0 |
| NPR001_34279 | ARFg | 360 | 9 | 1098.2 |
| NPR001_31927 | ARFg | 360 | 7 | 1345.7 |
| NPR001_DUM01 | ARFg | 360 | 9 | 1397.8 |
| NPR001_13848 | ARFi | 720 | 16 | 1348.0 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 270 | 7 | 4.3 |
| TER010_02189 | ARFa | 120 | 6 | 26.7 |
| NPR056_01297 | ARFb | 180 | 4 | 13.1 |
| TER012_00000 | ARFb | 120 | 6 | 43.3 |
| KOB024_00430 | ARFb | 120 | 8 | 33.0 |
| TER001_05833 | ARFc | 270 | 2 | 179.4 |
| KOB018_05953 | ARFc | 270 | 7 | 129.0 |
| NPR011_DUM01 | ARFc | 270 | 8 | 187.9 |
| LAC001_11829 | ARFc | 120 | 1 | 157.6 |

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| NPR001_DUM03 | ARFc | 120 | 6 | 185.2 |
| TER001_04450 | ARFd | 270 | 2 | 275.1 |
| KOB018_02518 | ARFd | 270 | 7 | 248.8 |
| TER001_01661 | ARFd | 270 | 7 | 354.0 |
| NPR001_49127 | ARFd | 270 | 2 | 408.0 |
| LAC001_11544 | ARFe | 270 | 9 | 409.8 |
| KOB001_10541 | ARFe | 270 | 2 | 461.0 |
| KOB001_09533 | ARFe | 270 | 7 | 521.1 |
| KOB001_DUM01 | ARFe | 270 | 7 | 609.2 |
| LAC001_05600 | ARFe | 270 | 7 | 658.1 |
| LAC001_04181 | ARFe | 270 | 7 | 694.6 |
| NPR001_DUM02 | ARFf | 270 | 7 | 1180.3 |
| NPR001_41506 | ARFf | 270 | 7 | 1202.6 |
| NPR001_40819 | ARFf | 270 | 7 | 1307.9 |
| NPR001_38235 | ARFg | 270 | 7 | 1256.1 |
| NPR001_34279 | ARFg | 270 | 1 | 1312.5 |
| NPR001_31927 | ARFg | 270 | 1 | 1600.2 |
| NPR001_DUM01 | ARFg | 360 | 9 | 1704.6 |
| NPR001_13848 | ARFi | 720 | 17 | 1713.5 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 270 | 7 | 4.6 |
| TER010_02189 | ARFa | 120 | 6 | 30.1 |
| NPR056_01297 | ARFb | 180 | 4 | 13.8 |
| TER012_00000 | ARFb | 120 | 6 | 48.9 |
| KOB024_00430 | ARFb | 120 | 8 | 35.9 |
| TER001_05833 | ARFc | 270 | 2 | 204.3 |
| KOB018_05953 | ARFc | 270 | 2 | 139.9 |
| NPR011_DUM01 | ARFc | 270 | 8 | 216.1 |
| LAC001_11829 | ARFc | 270 | 7 | 172.8 |
| NPR001_DUM03 | ARFc | 270 | 8 | 210.8 |
| TER001_04450 | ARFd | 270 | 2 | 313.5 |
| KOB018_02518 | ARFd | 270 | 2 | 276.8 |
| TER001_01661 | ARFd | 270 | 7 | 401.9 |
| NPR001_49127 | ARFd | 270 | 2 | 462.7 |
| LAC001_11544 | ARFe | 270 | 7 | 464.0 |
| KOB001_10541 | ARFe | 270 | 7 | 512.3 |
| KOB001_09533 | ARFe | 270 | 7 | 577.7 |
| KOB001_DUM01 | ARFe | 270 | 7 | 680.0 |
| LAC001_05600 | ARFe | 270 | 7 | 733.5 |

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| LAC001_04181 | ARFe | 270 | 7 | 775.8 |
| NPR001_DUM02 | ARFf | 270 | 7 | 1325.4 |
| NPR001_41506 | ARFf | 270 | 7 | 1354.4 |
| NPR001_40819 | ARFf | 270 | 7 | 1479.9 |
| NPR001_38235 | ARFg | 270 | 2 | 1498.5 |
| NPR001_34279 | ARFg | 270 | 8 | 1589.0 |
| NPR001_31927 | ARFg | 270 | 8 | 1909.8 |
| NPR001_DUM01 | ARFg | 360 | 3 | 2003.5 |
| NPR001_13848 | ARFi | 720 | 17 | 1973.8 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 270 | 9 | 6.4 |
| TER010_02189 | ARFa | 180 | 6 | 45.8 |
| NPR056_01297 | ARFb | 120 | 8 | 30.1 |
| TER012_00000 | ARFb | 120 | 6 | 74.7 |
| KOB024_00430 | ARFb | 120 | 1 | 57.6 |
| TER001_05833 | ARFc | 270 | 4 | 295.1 |
| KOB018_05953 | ARFc | 270 | 9 | 213.4 |
| NPR011_DUM01 | ARFc | 270 | 8 | 308.6 |
| LAC001_11829 | ARFc | 120 | 6 | 260.4 |
| NPR001_DUM03 | ARFc | 120 | 6 | 310.2 |
| TER001_04450 | ARFd | 270 | 8 | 452.5 |
| KOB018_02518 | ARFd | 270 | 7 | 385.7 |
| TER001_01661 | ARFd | 270 | 2 | 578.8 |
| NPR001_49127 | ARFd | 270 | 8 | 666.0 |
| LAC001_11544 | ARFe | 270 | 8 | 670.0 |
| KOB001_10541 | ARFe | 270 | 7 | 745.7 |
| KOB001_09533 | ARFe | 270 | 2 | 825.9 |
| KOB001_DUM01 | ARFe | 270 | 7 | 990.5 |
| LAC001_05600 | ARFe | 270 | 2 | 1057.1 |
| LAC001_04181 | ARFe | 270 | 2 | 1123.1 |
| NPR001_DUM02 | ARFf | 270 | 7 | 1896.9 |
| NPR001_41506 | ARFf | 270 | 7 | 1939.5 |
| NPR001_40819 | ARFf | 270 | 7 | 2121.6 |
| NPR001_38235 | ARFg | 270 | 1 | 2029.1 |
| NPR001_34279 | ARFg | 360 | 10 | 2200.5 |
| NPR001_31927 | ARFg | 360 | 3 | 2728.8 |
| NPR001_DUM01 | ARFg | 360 | 3 | 2902.7 |
| NPR001_13848 | ARFi | 720 | 16 | 2705.0 |

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

| Design Event Modelling Point Name | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) | 2020 Conditions Peak Discharge ($m^3/s$) |
|---|---|---|---|---|
| KOB032_00957 | ARFa | 270 | 9 | 7.0 |
| TER010_02189 | ARFa | 180 | 8 | 52.1 |
| NPR056_01297 | ARFb | 120 | 8 | 39.0 |
| TER012_00000 | ARFb | 120 | 6 | 84.0 |
| KOB024_00430 | ARFb | 90 | 9 | 66.1 |
| TER001_05833 | ARFc | 270 | 8 | 328.3 |
| KOB018_05953 | ARFc | 270 | 2 | 250.6 |
| NPR011_DUM01 | ARFc | 270 | 4 | 344.8 |
| LAC001_11829 | ARFc | 120 | 8 | 289.1 |
| NPR001_DUM03 | ARFc | 120 | 6 | 344.9 |
| TER001_04450 | ARFd | 270 | 8 | 497.1 |
| KOB018_02518 | ARFd | 270 | 7 | 445.7 |
| TER001_01661 | ARFd | 270 | 2 | 636.3 |
| NPR001_49127 | ARFd | 270 | 4 | 724.5 |
| LAC001_11544 | ARFe | 120 | 8 | 737.5 |
| KOB001_10541 | ARFe | 270 | 7 | 819.5 |
| KOB001_09533 | ARFe | 270 | 7 | 926.2 |
| KOB001_DUM01 | ARFe | 270 | 7 | 1090.8 |
| LAC001_05600 | ARFe | 270 | 2 | 1161.1 |
| LAC001_04181 | ARFe | 270 | 2 | 1233.8 |
| NPR001_DUM02 | ARFf | 270 | 7 | 2068.8 |
| NPR001_41506 | ARFf | 270 | 7 | 2116.5 |
| NPR001_40819 | ARFf | 270 | 7 | 2317.7 |
| NPR001_38235 | ARFg | 360 | 3 | 2248.3 |
| NPR001_34279 | ARFg | 360 | 3 | 2423.0 |
| NPR001_31927 | ARFg | 360 | 3 | 2990.6 |
| NPR001_DUM01 | ARFg | 360 | 3 | 3191.7 |
| NPR001_13848 | ARFi | 720 | 20 | 2979.6 |

## 4.2 The selection method for the sub-set of the critical events

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

[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 the Upper Pine River catchment.

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, 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 Critical Duration and Temporal Pattern 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 percentage

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 **Error! Reference source not found.**, 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.

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

| 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 Matrix with selected simulation and the maximum relative difference ratios.

## 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:

- Preference was given to the critical events that have a relative difference ratio greater than 0%. For example, ARFc 180 (TP8) in the 20% AEP was preferred over ARFd 180 (TP8) as points at higher in the top of catchment (near the top of the table) and were closer to 0%.
- The 5%, 2%, 1% AEP used non-critical events. The non-critical events were selected out of a library of critical temporal patterns. For the 5% AEP, a non-critical event allowed TER010_02189 to be within the target range whilst not allowing other Design Event Modelling points outside this range. For the 2% and 1% AEP, a 360-minute event was included as storage dominated locations in the headwaters caused lower magnitude AEP events to be higher in the hydraulic model (the 5% was higher for the 2% AEP, and the 2% was higher for the 1% AEP). The 180-minute in the 1% AEP was included for the same reason. All non-critical events headers in the results are shown by not being highlighted in bold.
- LAC001_11544 was higher than the upper bound for the 2% and 1% AEP. Given that this point was one location, and the upstream and downstream points were within the target range, this was acceptable.
- Multiple locations along Laceys Creek and North Pine River (in the middle of the catchment) are higher than the upper bound of the target range in the 0.1% and 0.05% AEP. A trade-off between being within tolerance or being too low in the top of the catchment was made, where the former was chosen. Noting the library of all critical temporal patterns (non-critical events) also had this trade-off.

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

| AEP | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) |
|---|---|---|---|
| 20% | ARFc | 180 | 3 |
| | ARFc | 270 | 1 |
| | ARFi | 1080 | 17 |

| AEP | Grouping | Duration (minutes) | TP (Point 1- 10, Areal 11- 20) |
|---|---|---|---|
| 10% | ARFa | 180 | 1 |
| | ARFd | 180 | 8 |
| | ARFi | 1080 | 19 |
| 5% | ARFa[1] | 360 | 2 |
| | ARFd | 180 | 8 |
| 2% | ARFa | 120 | 6 |
| | ARFd[1] | 360 | 9 |
| 1% | ARFa[1] | 180 | 8 |
| | ARFb | 120 | 6 |
| | ARFd | 270 | 7 |
| | ARFd[1] | 360 | 9 |
| 0.1% | ARFb | 120 | 6 |
| | ARFf | 360 | 3 |
| 0.05% | ARFb | 120 | 6 |
| | ARFf | 360 | 3 |

1 Non-critical event

| | ARFa_180 (TP1) | ARFa_180 (TP9) | ARFb_180 (TP1) | ARFb_180 (TP3) | ARFb_180 (TP6) | ARFc_270 (TP1) | ARFc_180 (TP3) | ARFc_180 (TP6) | ARFc_270 (TP5) | ARFc_270 (TP7) | ARFd_270 (TP7) | ARFe_270 (TP5) | ARFe_270 (TP7) | ARFf_270 (TP7) | ARFf_540 (TP7) | ARFg_360 (TP5) | ARFg_540 (TP7) | ARFi_1080 (TP17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KOB032_00957** | 0.0% | 3.2% | -1.9% | -0.8% | -9.3% | -7.7% | -4.6% | -12.0% | -17.0% | -13.3% | -15.4% | -19.7% | -17.5% | -19.7% | -22.5% | -24.2% | -23.6% | -54.1% |
| **TER010_02189** | 15.7% | 0.0% | 11.9% | 7.4% | -9.6% | -10.1% | 0.4% | -12.7% | -16.5% | -10.1% | -12.3% | -20.5% | -14.8% | -17.6% | -34.0% | -31.9% | -35.3% | -63.2% |
| **NPR056_01297** | 1.6% | 7.4% | 0.0% | 1.2% | -2.1% | -3.5% | -2.3% | -4.6% | -7.9% | -4.4% | -6.1% | -10.6% | -7.8% | -9.6% | -13.0% | -15.8% | -14.0% | -44.9% |
| **TER012_00000** | 10.5% | 13.3% | 6.4% | 7.5% | 0.0% | -5.0% | 0.0% | -4.1% | -10.2% | -5.1% | -7.8% | -14.6% | -10.6% | -13.8% | -25.4% | -27.1% | -26.9% | -58.8% |
| **KOB024_00430** | 1.5% | 18.6% | -1.9% | 0.0% | 3.8% | -5.8% | -6.6% | -0.6% | -6.4% | -0.7% | -3.5% | -11.0% | -6.4% | -9.6% | -17.1% | -24.7% | -18.8% | -52.2% |
| **TER001_05833** | 8.5% | 25.1% | 5.0% | 7.3% | 6.7% | 0.0% | 0.4% | 2.1% | -3.1% | 1.5% | -1.4% | -8.0% | -4.2% | -7.6% | -12.0% | -19.7% | -13.9% | -49.2% |
| **KOB018_05953** | 1.9% | 12.1% | -0.4% | 1.3% | 2.4% | -3.0% | -3.3% | -0.8% | -3.3% | 0.0% | -1.9% | -7.7% | -4.2% | -7.2% | -10.7% | -21.3% | -12.6% | -47.0% |
| **NPR011_DUM01** | 8.8% | 23.6% | 5.1% | 7.1% | 6.0% | -0.5% | 0.0% | 1.5% | -3.9% | 0.8% | -2.1% | -8.7% | -5.0% | -8.4% | -14.1% | -21.0% | -15.9% | -50.7% |
| **LAC001_11829** | 5.7% | 22.7% | 1.9% | 3.7% | 7.9% | -3.5% | -3.4% | 3.1% | 0.0% | 5.1% | 2.1% | -5.1% | -1.0% | -4.6% | -11.3% | -22.2% | -13.2% | -46.4% |
| **NPR001_DUM03** | 4.8% | 18.9% | 1.0% | 2.6% | 4.4% | -5.0% | -4.6% | 0.0% | -5.5% | -0.3% | -3.1% | -10.2% | -6.0% | -9.4% | -18.4% | -25.0% | -20.0% | -53.1% |
| **TER001_04450** | 5.2% | 24.6% | 1.9% | 4.5% | 7.1% | -1.7% | -2.0% | 2.4% | -2.1% | 2.9% | 0.0% | -7.0% | -2.9% | -6.3% | -10.8% | -19.9% | -12.7% | -47.4% |
| **KOB018_02518** | 5.6% | 20.8% | 3.1% | 6.1% | 5.2% | -0.1% | 0.8% | 0.9% | -2.0% | 2.7% | 0.0% | -7.0% | -2.7% | -6.0% | -6.9% | -17.9% | -9.0% | -41.9% |
| **TER001_01661** | -0.6% | 18.8% | -3.0% | 0.7% | 3.6% | -6.3% | -4.8% | -1.1% | -3.0% | 2.9% | 0.0% | -8.1% | -2.9% | -6.3% | -10.0% | -21.1% | -12.0% | -42.6% |
| **NPR001_49127** | 8.6% | 26.4% | 5.1% | 7.5% | 8.1% | 0.2% | 0.6% | 3.4% | -1.8% | 2.9% | 0.0% | -6.8% | -2.9% | -6.3% | -10.3% | -19.0% | -12.1% | -47.2% |
| **LAC001_11544** | 10.7% | 28.9% | 6.9% | 8.7% | 12.9% | 2.2% | 1.4% | 8.0% | 5.4% | 10.8% | 7.6% | 0.0% | 4.3% | 0.6% | -4.7% | -16.7% | -6.6% | -41.5% |
| **KOB001_10541** | 5.2% | 24.3% | 1.9% | 4.2% | 7.8% | -1.1% | -2.4% | 3.1% | 1.0% | 6.0% | 3.0% | -4.1% | 0.0% | -3.5% | -5.9% | -18.6% | -7.9% | -42.0% |
| **KOB001_09533** | 4.4% | 24.0% | 1.2% | 4.0% | 7.5% | -1.4% | -2.4% | 2.8% | 0.9% | 6.0% | 3.0% | -4.2% | 0.0% | -3.5% | -5.2% | -18.4% | -7.2% | -40.7% |
| **KOB001_DUM01** | 4.8% | 23.0% | 2.0% | 6.0% | 6.8% | -0.6% | 0.0% | 2.0% | 0.7% | 5.9% | 2.9% | -4.4% | 0.0% | -3.4% | -3.5% | -17.2% | -5.6% | -37.0% |
| **LAC001_05600** | 6.1% | 25.4% | 3.0% | 6.4% | 8.2% | -0.5% | 0.0% | 3.3% | 1.0% | 6.0% | 3.0% | -4.2% | 0.0% | -3.5% | -3.9% | -17.5% | -6.0% | -38.7% |
| **LAC001_04181** | 5.9% | 25.1% | 2.9% | 6.6% | 7.9% | -0.5% | 0.4% | 3.1% | 0.9% | 6.0% | 3.0% | -4.3% | 0.0% | -3.5% | -3.6% | -17.4% | -5.7% | -37.8% |
| **NPR001_DUM02** | 10.1% | 27.2% | 7.5% | 11.0% | 10.7% | 2.3% | 5.0% | 5.6% | 3.8% | 9.6% | 6.5% | -1.5% | 3.5% | 0.0% | 0.8% | -13.7% | -1.4% | -34.0% |
| **NPR001_41506** | 10.6% | 26.1% | 7.9% | 11.2% | 10.1% | 2.4% | 5.1% | 5.1% | 3.6% | 9.6% | 6.5% | -1.7% | 3.5% | 0.0% | 1.7% | -12.2% | -0.5% | -32.8% |
| **NPR001_40819** | 8.3% | 20.4% | 5.7% | 8.3% | 5.4% | -0.3% | 2.4% | 0.6% | -0.2% | 5.9% | 2.9% | -5.4% | 0.1% | -3.3% | 0.0% | -11.9% | -2.1% | -32.9% |
| **NPR001_38235** | 9.2% | 21.0% | 6.6% | 9.2% | 6.7% | 2.3% | 3.3% | 1.8% | 1.8% | 8.4% | 5.4% | -3.5% | 2.5% | -1.0% | 2.2% | -8.0% | 0.0% | -30.3% |
| **NPR001_34279** | 10.4% | 20.3% | 7.8% | 10.1% | 7.3% | 7.8% | 4.2% | 2.3% | 4.0% | 11.4% | 8.3% | -1.5% | 5.2% | 1.7% | 6.4% | 0.0% | 4.1% | -24.8% |
| **NPR001_31927** | 3.2% | 9.6% | 0.9% | 2.5% | 0.0% | 3.7% | -2.8% | -4.7% | 2.1% | 9.5% | 6.3% | -3.4% | 3.3% | -0.3% | 4.3% | 0.0% | 2.0% | -23.4% |
| **NPR001_DUM01** | -0.4% | 4.9% | -2.5% | -1.2% | -3.4% | 2.8% | -6.1% | -7.9% | 0.1% | 6.9% | 3.8% | -5.3% | 0.8% | -2.7% | 4.9% | 0.0% | 2.5% | -18.6% |
| **NPR001_13848** | -20.7% | -19.9% | -21.9% | -21.4% | -22.6% | -13.5% | -24.7% | -25.9% | -13.9% | -12.1% | -14.2% | 8.5% | 10.4% | 6.7% | 34.5% | 20.3% | 31.8% | 0.0% |

Figure 4.5 Results matrix for the 20% AEP

| | ARFa_180 (TP1) | ARFa_180 (TP4) | ARFb_180 (TP4) | ARFb_180 (TP8) | ARFc_180 (TP4) | ARFc_180 (TP6) | ARFc_180 (TP8) | ARFd_180 (TP4) | ARFd_180 (TP8) | ARFe_180 (TP4) | ARFe_180 (TP8) | ARFf_180 (TP4) | ARFf_360 (TP7) | ARFg_360 (TP7) | ARFg_360 (TP9) | ARFg_360 (TP10 | ARFi_1080 (TP19) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KOB032_00957** | -11.1% | 0.0% | -1.4% | -0.6% | -5.1% | -2.1% | -4.0% | -7.6% | -6.2% | -9.8% | -8.2% | -12.5% | -16.1% | -19.1% | -18.6% | -19.3% | -48.0% |
| **TER010_02189** | 0.0% | 9.4% | 7.4% | -4.7% | 1.4% | -13.1% | -8.6% | -3.2% | -11.1% | -7.5% | -13.5% | -12.6% | -17.5% | -21.5% | -26.0% | -28.3% | -61.0% |
| **NPR056_01297** | -6.9% | 1.4% | 0.2% | 0.0% | -3.1% | -0.8% | -3.0% | -5.3% | -5.0% | -7.3% | -6.7% | -9.7% | -15.3% | -17.7% | -13.5% | -14.4% | -41.3% |
| **TER012_00000** | -13.2% | 2.1% | 0.0% | 2.1% | -5.9% | -3.7% | -2.7% | -10.1% | -5.8% | -14.1% | -8.7% | -18.8% | -16.0% | -20.3% | -23.6% | -26.2% | -58.5% |
| **KOB024_00430** | -18.6% | 2.0% | 0.0% | 2.0% | -5.2% | -2.1% | -2.9% | -8.9% | -6.1% | -12.3% | -9.0% | -16.4% | -21.2% | -24.9% | -22.6% | -21.9% | -53.5% |
| **TER001_05833** | -13.7% | 7.8% | 5.7% | 6.1% | 0.0% | 3.3% | 0.9% | -4.0% | -2.5% | -7.6% | -5.6% | -12.0% | -18.0% | -21.6% | -17.5% | -18.1% | -52.1% |
| **KOB018_05953** | -6.6% | 5.7% | 4.1% | 3.6% | 0.1% | 2.2% | 0.0% | -2.7% | -2.3% | -4.6% | -3.9% | -6.6% | -11.6% | -14.5% | -8.8% | -9.4% | -42.3% |
| **NPR011_DUM01** | -13.7% | 7.7% | 5.6% | 7.5% | 0.0% | 3.4% | 2.3% | -4.0% | -1.1% | -7.6% | -4.2% | -12.0% | -15.6% | -19.6% | -17.4% | -18.5% | -52.0% |
| **LAC001_11829** | -13.0% | 4.1% | 2.0% | 5.2% | -3.5% | 0.2% | 0.0% | -7.3% | -3.4% | -10.9% | -6.5% | -15.2% | -18.3% | -22.1% | -17.3% | -19.7% | -50.1% |
| **NPR001_DUM03** | -15.4% | 3.6% | 1.6% | 5.3% | -3.7% | 0.0% | 0.2% | -7.5% | -3.1% | -10.9% | -6.1% | -15.1% | -17.4% | -21.3% | -19.9% | -21.6% | -54.0% |
| **TER001_04450** | -8.8% | 12.3% | 10.1% | 10.2% | 4.1% | 7.7% | 4.7% | 0.0% | 1.2% | -3.8% | -2.1% | -8.4% | -15.8% | -19.4% | -12.8% | -13.6% | -48.9% |
| **KOB018_02518** | -5.1% | 10.1% | 8.4% | 6.8% | 3.9% | 6.3% | 2.7% | 0.7% | 0.0% | -2.4% | -2.6% | -6.3% | -11.5% | -14.4% | -9.3% | -8.7% | -41.3% |
| **TER001_01661** | -5.1% | 14.0% | 11.2% | 10.2% | 4.5% | 7.4% | 4.1% | 0.0% | 0.1% | -3.9% | -3.4% | -8.2% | -12.4% | -15.6% | -8.7% | -8.3% | -43.9% |
| **NPR001_49127** | -9.6% | 12.3% | 10.1% | 10.5% | 4.1% | 7.8% | 5.0% | 0.0% | 1.5% | -3.8% | -1.7% | -8.4% | -15.0% | -18.8% | -13.7% | -14.6% | -48.7% |
| **LAC001_11544** | -6.6% | 11.9% | 9.7% | 12.5% | 3.8% | 7.7% | 6.9% | -0.4% | 3.3% | -4.2% | 0.0% | -8.8% | -11.9% | -16.0% | -10.0% | -12.8% | -44.3% |
| **KOB001_10541** | -3.5% | 16.8% | 14.5% | 15.1% | 8.3% | 12.1% | 9.4% | 4.0% | 5.7% | 0.0% | 2.3% | -4.8% | -10.6% | -14.5% | -5.9% | -7.6% | -41.1% |
| **KOB001_09533** | -3.0% | 16.9% | 14.5% | 14.4% | 8.3% | 11.8% | 8.7% | 4.0% | 5.0% | 0.0% | 1.6% | -4.7% | -11.6% | -15.3% | -5.7% | -6.9% | -40.4% |
| **KOB001_DUM01** | -1.4% | 16.8% | 14.3% | 13.7% | 8.1% | 10.9% | 8.0% | 3.9% | 4.2% | 0.0% | 0.8% | -4.6% | -7.1% | -10.7% | -4.0% | -3.4% | -37.7% |
| **LAC001_05600** | -2.7% | 17.0% | 14.6% | 13.7% | 8.3% | 11.3% | 7.9% | 4.0% | 4.2% | 0.0% | 0.8% | -4.7% | -11.8% | -15.1% | -6.6% | -6.7% | -39.9% |
| **LAC001_04181** | -2.6% | 17.0% | 14.6% | 13.5% | 8.3% | 11.1% | 7.7% | 4.0% | 4.0% | 0.0% | 0.6% | -4.7% | -10.5% | -13.9% | -6.2% | -5.9% | -39.2% |
| **NPR001_DUM02** | 3.7% | 22.6% | 20.0% | 18.9% | 13.4% | 16.3% | 12.9% | 9.0% | 8.9% | 4.9% | 5.3% | 0.0% | -1.9% | -5.7% | -0.1% | 1.2% | -34.4% |
| **NPR001_41506** | 4.4% | 22.6% | 20.0% | 19.0% | 13.4% | 16.1% | 12.8% | 9.0% | 8.9% | 4.9% | 5.2% | 0.0% | -0.3% | -4.0% | 0.7% | 2.1% | -32.8% |
| **NPR001_40819** | 3.0% | 19.0% | 16.5% | 15.5% | 10.1% | 12.6% | 9.5% | 5.8% | 5.7% | 1.9% | 2.1% | -2.9% | 0.0% | -3.7% | -0.6% | 1.2% | -32.2% |
| **NPR001_38235** | 5.8% | 20.8% | 18.2% | 17.3% | 11.7% | 14.1% | 11.2% | 7.3% | 7.3% | 3.3% | 3.6% | -1.4% | 3.7% | 0.0% | 2.3% | 3.8% | -29.2% |
| **NPR001_34279** | 2.8% | 14.8% | 12.3% | 11.6% | 6.1% | 8.2% | 5.7% | 2.0% | 1.9% | -1.8% | -1.6% | -6.3% | 4.7% | 1.0% | 0.0% | 1.2% | -27.6% |
| **NPR001_31927** | 0.2% | 7.7% | 5.4% | 4.9% | -0.4% | 1.2% | -0.7% | -4.3% | -4.4% | -7.8% | -7.7% | -12.2% | 4.4% | 0.8% | 0.4% | 0.0% | -26.5% |
| **NPR001_DUM01** | -1.2% | 5.2% | 2.9% | 2.4% | -2.9% | -1.5% | -3.2% | -6.7% | -6.8% | -10.2% | -10.2% | -14.5% | 5.8% | 2.2% | 0.9% | 0.0% | -20.6% |
| **NPR001_13848** | -18.9% | -18.1% | -19.6% | -19.8% | -23.3% | -23.0% | -23.4% | -25.7% | -25.7% | -3.4% | -3.4% | -7.7% | 31.9% | 27.9% | 27.7% | 26.3% | 0.0% |

Figure 4.6 Results matrix for the 10% AEP

| | ARFa_180 (TP4) | ARFb_180 (TP4) | ARFb_180 (TP6) | ARFb_180 (TP8) | ARFc_180 (TP4) | ARFc_180 (TP6) | ARFc_180 (TP8) | ARFd_180 (TP4) | ARFd_180 (TP8) | ARFe_180 (TP8) | ARFf_180 (TP8) | ARFg_360 (TP7) | ARFg_360 (TP9) | ARFi_720 (TP16) | ARFa_360 (TP2) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KOB032_00957 | 0.0% | -2.1% | 1.0% | -0.2% | -6.9% | -2.8% | -4.4% | -9.7% | -6.9% | -9.2% | -12.0% | -23.5% | -19.6% | -40.4% | -7.8% |
| TER010_02189 | 0.0% | -3.2% | -6.4% | -2.1% | -10.4% | -12.2% | -10.0% | -14.7% | -15.5% | -20.0% | -22.9% | -30.9% | -31.8% | -56.9% | 0.7% |
| NPR056_01297 | 1.0% | 0.0% | 1.6% | 0.5% | -3.6% | -0.5% | -2.3% | -6.2% | -4.6% | -6.7% | -9.1% | -19.2% | -14.6% | -31.9% | -8.8% |
| TER012_00000 | 0.7% | -2.6% | 0.0% | 1.2% | -9.8% | -5.3% | -4.3% | -14.1% | -7.5% | -10.5% | -14.1% | -24.6% | -26.0% | -52.2% | 3.4% |
| KOB024_00430 | -1.8% | -4.4% | 0.5% | 0.0% | -10.4% | -4.9% | -5.4% | -14.1% | -8.7% | -11.7% | -15.3% | -30.2% | -26.9% | -48.6% | -8.7% |
| TER001_05833 | 5.6% | 2.7% | 7.8% | 5.8% | -4.0% | 1.9% | 0.0% | -8.0% | -3.5% | -6.8% | -10.6% | -24.4% | -20.0% | -45.0% | -1.9% |
| KOB018_05953 | 8.2% | 5.7% | 9.4% | 6.4% | 0.0% | 4.0% | 1.4% | -3.4% | -1.6% | -4.3% | -7.3% | -16.4% | -12.2% | -31.5% | -4.9% |
| NPR011_DUM01 | 4.0% | 1.2% | 6.6% | 5.8% | -5.4% | 0.9% | 0.0% | -9.3% | -3.5% | -6.7% | -10.5% | -23.9% | -21.0% | -46.0% | 0.2% |
| LAC001_11829 | 3.0% | 0.1% | 5.8% | 6.0% | -6.4% | 0.0% | 0.1% | -10.2% | -3.4% | -6.7% | -10.6% | -25.1% | -19.9% | -43.8% | -3.3% |
| NPR001_DUM03 | 2.5% | -0.2% | 5.7% | 6.3% | -6.6% | 0.0% | 0.5% | -10.4% | -3.0% | -6.2% | -10.0% | -23.8% | -21.4% | -46.8% | 1.4% |
| TER001_04450 | 10.1% | 7.1% | 12.5% | 9.8% | 0.2% | 6.3% | 3.7% | -4.0% | 0.0% | -3.4% | -7.5% | -22.0% | -15.8% | -41.5% | -0.8% |
| KOB018_02518 | 11.3% | 8.6% | 12.6% | 8.6% | 2.3% | 6.8% | 3.0% | -1.1% | 0.0% | -2.7% | -5.9% | -16.0% | -10.8% | -31.8% | -5.7% |
| TER001_01661 | 16.4% | 12.9% | 18.0% | 14.1% | 4.5% | 10.5% | 6.6% | 0.0% | 2.3% | -1.5% | -6.2% | -18.7% | -10.9% | -35.6% | -5.7% |
| NPR001_49127 | 9.7% | 6.7% | 12.1% | 9.7% | -0.3% | 5.9% | 3.7% | -4.4% | 0.0% | -3.4% | -7.4% | -22.1% | -16.9% | -42.0% | 0.9% |
| LAC001_11544 | 11.0% | 8.0% | 14.1% | 13.6% | 1.0% | 7.8% | 7.3% | -3.2% | 3.5% | 0.0% | -4.2% | -18.9% | -12.7% | -37.7% | 4.4% |
| KOB001_10541 | 13.6% | 10.5% | 15.9% | 13.8% | 3.3% | 9.5% | 7.4% | -1.1% | 3.5% | 0.0% | -4.2% | -18.5% | -10.5% | -35.1% | 3.1% |
| KOB001_09533 | 14.6% | 11.5% | 16.7% | 13.8% | 4.3% | 10.2% | 7.4% | -0.1% | 3.5% | 0.0% | -4.2% | -18.5% | -9.6% | -33.8% | 1.5% |
| KOB001_DUM01 | 16.1% | 13.0% | 17.3% | 13.9% | 5.8% | 10.6% | 7.5% | 1.5% | 3.6% | 0.0% | -4.3% | -14.5% | -7.4% | -30.6% | -2.3% |
| LAC001_05600 | 16.1% | 12.9% | 17.5% | 13.8% | 5.5% | 10.9% | 7.4% | 1.1% | 3.6% | 0.0% | -4.2% | -18.7% | -9.9% | -33.3% | -0.9% |
| LAC001_04181 | 16.4% | 13.2% | 17.6% | 13.9% | 5.9% | 10.9% | 7.4% | 1.5% | 3.6% | 0.0% | -4.2% | -17.4% | -9.3% | -32.5% | -2.0% |
| NPR001_DUM02 | 22.0% | 18.7% | 22.8% | 19.2% | 11.1% | 15.7% | 12.4% | 6.6% | 8.3% | 4.5% | 0.0% | -9.7% | -3.6% | -27.0% | -0.2% |
| NPR001_41506 | 22.1% | 18.9% | 22.8% | 19.3% | 11.3% | 15.7% | 12.4% | 6.8% | 8.3% | 4.5% | 0.0% | -7.9% | -2.8% | -25.3% | 0.2% |
| NPR001_40819 | 22.5% | 19.2% | 22.8% | 19.4% | 11.7% | 15.6% | 12.5% | 7.2% | 8.4% | 4.5% | 0.0% | -4.7% | -1.0% | -22.5% | 0.9% |
| NPR001_38235 | 22.3% | 19.1% | 22.5% | 19.3% | 11.5% | 15.3% | 12.3% | 7.0% | 8.2% | 4.3% | -0.2% | -3.1% | 0.0% | -20.6% | 2.7% |
| NPR001_34279 | 19.0% | 15.9% | 18.9% | 16.1% | 8.6% | 11.8% | 9.3% | 4.2% | 5.2% | 1.4% | -3.1% | 0.3% | 0.0% | -17.1% | 7.3% |
| NPR001_31927 | 11.1% | 8.4% | 10.4% | 8.4% | 1.8% | 3.9% | 2.1% | -2.2% | -1.6% | -5.1% | -9.2% | 0.0% | 0.2% | -15.9% | 4.5% |
| NPR001_DUM01 | 7.7% | 5.0% | 6.7% | 5.0% | -1.4% | 0.4% | -1.1% | -5.2% | -4.8% | -8.1% | -12.2% | 1.2% | 0.0% | -10.5% | 8.0% |
| NPR001_13848 | -15.1% | -16.8% | -16.5% | -16.8% | -21.0% | -20.6% | -20.9% | -23.5% | -23.4% | 3.8% | -0.8% | 35.0% | 35.2% | 0.0% | 1.1% |

Figure 4.7 Results matrix for the 5% AEP

| | ARFa_120 (TP6) | ARFa_270 (TP7) | ARFb_120 (TP6) | ARFb_120 (TP8) | ARFb_180 (TP4) | ARFc_120 (TP1) | ARFc_270 (TP2) | ARFc_120 (TP6) | ARFc_270 (TP7) | ARFc_270 (TP8) | ARFd_270 (TP2) | ARFd_270 (TP7) | ARFe_270 (TP2) | ARFe_270 (TP7) | ARFe_270 (TP9) | ARFf_270 (TP7) | ARFg_270 (TP1) | ARFg_270 (TP7) | ARFg_360 (TP9) | ARFi_720 (TP17) | ARFd_360 (TP9) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KOB032_00957 | -3.6% | 0.0% | -4.8% | -3.9% | -4.4% | -6.6% | -4.4% | -8.2% | -4.8% | -4.1% | -6.2% | -6.7% | -8.1% | -9.0% | -13.3% | -12.2% | -13.4% | -15.6% | -18.7% | -33.3% | -10.3% |
| TER010_02189 | 0.0% | -7.2% | -3.6% | -11.8% | -9.5% | -8.8% | -25.5% | -13.4% | -17.1% | -22.3% | -28.9% | -20.8% | -31.7% | -23.6% | -20.0% | -27.0% | -25.6% | -32.2% | -31.0% | -51.2% | -12.3% |
| NPR056_01297 | -0.1% | 1.7% | -1.3% | -0.6% | 0.0% | -3.0% | -0.8% | -3.9% | -2.1% | -0.1% | -2.4% | -3.7% | -3.8% | -5.6% | -7.6% | -8.6% | -8.1% | -11.5% | -16.3% | -27.1% | -9.4% |
| TER012_00000 | 2.9% | 4.1% | 0.0% | -2.7% | 0.6% | -3.4% | -11.9% | -7.0% | -5.3% | -10.1% | -15.3% | -9.2% | -18.4% | -12.7% | -14.1% | -16.7% | -15.7% | -20.8% | -15.3% | -40.4% | -1.3% |
| KOB024_00430 | 1.9% | -1.0% | -1.1% | 0.0% | -5.3% | -4.2% | -12.7% | -8.3% | -10.0% | -12.5% | -15.9% | -13.7% | -18.9% | -17.0% | -20.0% | -20.8% | -20.8% | -24.7% | -24.4% | -40.8% | -12.2% |
| TER001_05833 | 2.0% | 13.4% | -0.9% | 1.5% | 5.0% | -4.1% | 0.0% | -8.1% | 3.1% | 0.8% | -3.6% | -1.1% | -7.0% | -4.9% | -12.9% | -9.3% | -9.8% | -13.7% | -12.9% | -34.1% | 0.7% |
| KOB018_05953 | -2.1% | 6.4% | -4.7% | -2.4% | -0.9% | -7.8% | 1.6% | -10.5% | 0.0% | 2.2% | -1.5% | -3.7% | -4.7% | -7.0% | -12.9% | -10.7% | -11.1% | -14.4% | -17.2% | -26.1% | -8.3% |
| NPR011_DUM01 | 6.0% | 13.3% | 2.9% | 4.4% | 6.6% | -0.2% | -1.4% | -4.4% | 3.1% | 0.0% | -5.0% | -1.1% | -8.3% | -5.0% | -10.8% | -9.4% | -9.4% | -13.8% | -11.4% | -33.7% | 2.6% |
| LAC001_11829 | 7.5% | 9.3% | 4.3% | 4.2% | 1.1% | 0.0% | -3.4% | -3.4% | -0.7% | -1.9% | -6.9% | -4.8% | -10.2% | -8.5% | -10.1% | -12.8% | -11.0% | -17.1% | -15.6% | -33.7% | -2.4% |
| NPR001_DUM03 | 10.9% | 12.6% | 7.7% | 6.9% | 6.1% | 4.0% | -2.7% | 0.0% | 2.4% | -1.0% | -6.2% | -1.8% | -9.5% | -5.7% | -8.0% | -10.0% | -9.0% | -14.4% | -11.4% | -34.3% | 2.8% |
| TER001_04450 | 2.8% | 16.8% | -0.2% | 2.1% | 6.2% | -3.8% | 3.8% | -7.5% | 6.2% | 4.7% | 0.0% | 1.8% | -3.5% | -2.2% | -11.1% | -6.7% | -6.9% | -11.2% | -11.8% | -32.1% | 1.6% |
| KOB018_02518 | 2.1% | 13.4% | -0.7% | 2.0% | 4.2% | -4.4% | 6.1% | -7.1% | 3.9% | 6.9% | 2.4% | 0.0% | -0.9% | -3.5% | -9.8% | -7.6% | -7.2% | -11.6% | -15.9% | -25.8% | -6.2% |
| TER001_01661 | -4.3% | 15.0% | -7.5% | -4.9% | 2.4% | -12.1% | 4.6% | -15.7% | 4.4% | 4.7% | 0.6% | 0.0% | -3.1% | -4.0% | -15.8% | -8.6% | -9.2% | -13.3% | -17.7% | -33.8% | -4.3% |
| NPR001_49127 | 6.7% | 17.4% | 3.6% | 5.9% | 8.7% | 0.2% | 3.8% | -3.9% | 6.8% | 4.7% | 0.0% | 2.4% | -3.5% | -1.5% | -10.1% | -6.1% | -6.6% | -10.6% | -10.3% | -31.0% | 3.6% |
| LAC001_11544 | 18.7% | 23.0% | 15.1% | 15.2% | 12.8% | 10.5% | 8.8% | 6.7% | 11.8% | 10.8% | 4.8% | 7.2% | 1.1% | 3.0% | 0.0% | -1.8% | 0.0% | -6.6% | -4.9% | -23.9% | 9.9% |
| KOB001_10541 | 8.8% | 20.0% | 5.6% | 7.4% | 8.2% | 1.5% | 7.7% | -2.2% | 9.1% | 9.1% | 3.7% | 4.6% | 0.0% | 0.6% | -5.3% | -4.1% | -3.0% | -8.8% | -8.7% | -25.5% | 5.2% |
| KOB001_09533 | 6.0% | 19.3% | 2.9% | 5.1% | 7.2% | -1.2% | 7.8% | -4.8% | 8.5% | 9.1% | 3.8% | 4.1% | 0.1% | 0.0% | -7.2% | -4.6% | -3.5% | -9.2% | -10.3% | -25.9% | 3.0% |
| KOB001_DUM01 | 0.6% | 18.8% | -2.4% | 0.3% | 7.6% | -6.4% | 9.8% | -9.7% | 8.2% | 10.7% | 5.7% | 3.9% | 1.9% | 0.0% | -10.5% | -4.5% | -4.3% | -8.9% | -12.7% | -25.5% | -0.6% |
| LAC001_05600 | 5.4% | 19.2% | 2.3% | 5.3% | 8.3% | -1.7% | 8.9% | -5.3% | 8.4% | 9.7% | 4.8% | 4.0% | 1.1% | 0.0% | -9.5% | -4.6% | -3.9% | -9.1% | -11.5% | -25.9% | 1.2% |
| LAC001_04181 | 4.1% | 19.1% | 0.9% | 4.1% | 7.9% | -3.0% | 9.3% | -6.6% | 8.4% | 10.0% | 5.2% | 4.0% | 1.5% | 0.0% | -10.2% | -4.5% | -4.4% | -9.1% | -12.2% | -25.8% | 0.3% |
| NPR001_DUM02 | 3.9% | 24.4% | 0.8% | 3.8% | 13.9% | -3.6% | 15.5% | -6.8% | 13.4% | 15.6% | 11.3% | 8.8% | 7.3% | 4.7% | -7.6% | 0.0% | -1.8% | -4.7% | -9.9% | -22.6% | 2.1% |
| NPR001_41506 | 2.3% | 24.3% | -0.8% | 2.0% | 14.1% | -5.3% | 16.3% | -8.3% | 13.3% | 15.9% | 12.0% | 8.8% | 8.1% | 4.7% | -7.9% | 0.0% | -2.6% | -4.7% | -10.3% | -22.0% | 1.3% |
| NPR001_40819 | -0.5% | 24.1% | -3.6% | -0.9% | 14.9% | -8.1% | 17.4% | -10.9% | 13.2% | 16.6% | 13.1% | 8.7% | 9.1% | 4.6% | -4.6% | 0.0% | -3.5% | -4.6% | -11.0% | -21.1% | 0.1% |
| NPR001_38235 | 2.5% | 29.6% | -0.6% | 1.8% | 19.3% | -5.6% | 23.7% | -8.3% | 18.4% | 22.5% | 19.2% | 13.7% | 15.0% | 9.5% | 0.3% | 4.7% | 0.8% | 0.0% | -6.7% | -16.7% | 4.4% |
| NPR001_34279 | -1.3% | 30.2% | -4.4% | -2.3% | 17.8% | -9.6% | 25.5% | -11.8% | 19.4% | 23.3% | 20.9% | 14.9% | 16.6% | 10.9% | 2.4% | 6.3% | 0.0% | 1.7% | -5.1% | -14.7% | 5.3% |
| NPR001_31927 | -9.2% | 24.2% | -12.0% | -10.8% | 11.6% | -17.3% | 21.7% | -18.8% | 15.3% | 20.3% | 17.7% | 11.8% | 14.1% | 9.0% | 4.2% | 4.7% | 0.0% | 0.6% | -6.7% | -14.4% | 2.6% |
| NPR001_DUM01 | -14.8% | 24.3% | -17.5% | -16.5% | 6.4% | -22.7% | 18.0% | -23.8% | 15.5% | 16.4% | 14.2% | 12.1% | 10.9% | 8.9% | 1.3% | 4.4% | -3.2% | 0.0% | 0.0% | -12.2% | 9.0% |
| NPR001_13848 | -36.6% | -4.2% | -38.3% | -38.3% | -22.4% | -42.1% | -8.9% | -42.3% | -10.5% | -9.1% | -11.6% | -13.1% | 32.4% | 30.7% | 27.4% | 26.0% | 19.8% | 21.4% | 36.0% | 0.0% | -2.6% |

Figure 4.8 Results matrix for the 2% AEP

| | ARFa_120 (TP6) | ARFa_270 (TP7) | ARFb_120 (TP6) | ARFb_120 (TP8) | ARFb_180 (TP4) | ARFc_270 (TP2) | ARFc_270 (TP7) | ARFc_270 (TP8) | ARFd_270 (TP2) | ARFd_270 (TP7) | ARFe_270 (TP7) | ARFf_270 (TP7) | ARFg_270 (TP2) | ARFg_360 (TP3) | ARFg_270 (TP8) | ARFi_720 (TP17) | ARFa_180 (TP8) | ARFd_360 (TP9) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KOB032_00957 | -3.7% | 0.0% | -5.3% | -4.3% | -3.3% | -3.8% | -5.6% | -2.6% | -6.0% | -7.7% | -9.6% | -11.8% | -12.8% | -16.7% | -11.8% | -29.6% | -3.3% | -11.1% |
| TER010_02189 | 0.0% | -9.6% | -2.8% | -13.2% | -8.7% | -20.1% | -17.7% | -20.2% | -24.2% | -20.7% | -24.3% | -29.5% | -37.9% | -30.4% | -34.4% | -49.8% | -3.1% | -14.1% |
| NPR056_01297 | -1.2% | 0.3% | -2.5% | -1.8% | 0.0% | -1.7% | -4.3% | -0.6% | -3.6% | -6.0% | -7.5% | -9.4% | -9.3% | -11.7% | -8.3% | -25.5% | -0.4% | -10.7% |
| TER012_00000 | 3.2% | 3.9% | 0.0% | -3.0% | 0.3% | -11.0% | -6.5% | -8.4% | -14.7% | -10.5% | -14.0% | -18.4% | -26.2% | -24.5% | -23.5% | -37.6% | -1.9% | -4.5% |
| KOB024_00430 | 2.3% | -3.7% | -1.0% | 0.0% | -6.9% | -14.7% | -13.3% | -13.2% | -18.0% | -17.0% | -20.2% | -24.3% | -28.6% | -31.3% | -27.6% | -40.0% | -5.4% | -16.9% |
| TER001_05833 | 2.2% | 13.0% | -1.0% | 1.3% | 5.0% | 0.0% | 1.8% | 2.2% | -3.8% | -2.5% | -6.3% | -11.1% | -16.1% | -19.3% | -14.4% | -31.5% | -1.4% | -1.5% |
| KOB018_05953 | -3.2% | 5.5% | -5.2% | -3.6% | -1.1% | 0.0% | -2.6% | 1.8% | -2.8% | -5.4% | -7.8% | -12.0% | -13.0% | -15.9% | -11.3% | -27.0% | -2.0% | -10.0% |
| NPR011_DUM01 | 5.0% | 11.3% | 1.7% | 3.0% | 5.0% | -2.8% | 0.2% | 0.0% | -6.5% | -4.1% | -7.8% | -12.5% | -18.4% | -20.2% | -16.4% | -32.2% | 0.1% | -1.6% |
| LAC001_11829 | 11.2% | 11.1% | 7.6% | 7.3% | 3.1% | -1.3% | 0.0% | 1.5% | -5.1% | -4.3% | -8.0% | -12.8% | -17.3% | -18.2% | -15.2% | -30.0% | 5.2% | -2.9% |
| NPR001_DUM03 | 10.9% | 11.5% | 7.4% | 6.3% | 5.3% | -3.1% | 0.4% | 0.0% | -6.8% | -3.9% | -7.6% | -12.4% | -18.8% | -19.1% | -16.5% | -32.2% | 5.4% | -0.7% |
| TER001_04450 | 3.1% | 16.7% | -0.2% | 2.1% | 6.7% | 4.0% | 5.1% | 6.3% | 0.0% | 0.7% | -3.2% | -8.2% | -12.8% | -16.2% | -11.0% | -29.5% | 1.0% | 0.2% |
| KOB018_02518 | 0.6% | 9.8% | -2.4% | 0.3% | 2.5% | 3.5% | 0.5% | 5.3% | 0.0% | -3.4% | -6.8% | -11.2% | -12.0% | -15.4% | -10.3% | -27.2% | 2.2% | -9.5% |
| TER001_01661 | -2.7% | 15.8% | -6.0% | -3.2% | 4.6% | 5.5% | 4.5% | 6.8% | 1.4% | 0.0% | -3.9% | -8.8% | -11.8% | -15.9% | -10.4% | -30.3% | -2.5% | -3.2% |
| NPR001_49127 | 7.3% | 17.3% | 3.8% | 6.1% | 9.0% | 4.0% | 5.7% | 6.3% | 0.0% | 1.2% | -2.7% | -7.7% | -12.8% | -16.2% | -11.0% | -28.4% | 2.7% | 1.6% |
| LAC001_11544 | 18.6% | 20.7% | 14.7% | 14.6% | 11.2% | 7.3% | 8.7% | 10.6% | 3.2% | 4.0% | 0.0% | -5.2% | -10.0% | -10.8% | -7.6% | -22.5% | 12.7% | 5.5% |
| KOB001_10541 | 10.8% | 20.6% | 7.2% | 8.9% | 9.3% | 8.6% | 8.6% | 11.3% | 4.4% | 4.0% | 0.0% | -5.1% | -9.1% | -11.2% | -6.8% | -22.5% | 8.1% | 3.9% |
| KOB001_09533 | 8.3% | 20.6% | 4.7% | 7.0% | 8.9% | 9.2% | 8.6% | 11.8% | 5.0% | 4.0% | 0.0% | -5.1% | -8.5% | -11.1% | -6.3% | -22.7% | 6.6% | 2.7% |
| KOB001_DUM01 | 2.2% | 20.0% | -1.2% | 1.7% | 9.5% | 11.1% | 8.4% | 13.1% | 6.7% | 3.9% | 0.0% | -4.9% | -7.0% | -9.6% | -5.1% | -22.7% | 3.1% | -0.3% |
| LAC001_05600 | 7.4% | 20.4% | 3.8% | 7.0% | 10.1% | 10.1% | 8.6% | 12.2% | 5.8% | 4.0% | 0.0% | -5.1% | -7.8% | -10.8% | -5.9% | -22.8% | 5.0% | 1.2% |
| LAC001_04181 | 5.8% | 20.3% | 2.3% | 5.6% | 9.7% | 10.5% | 8.5% | 12.5% | 6.2% | 3.9% | 0.0% | -5.0% | -7.5% | -10.6% | -5.7% | -22.8% | 4.4% | 0.4% |
| NPR001_DUM02 | 5.5% | 26.3% | 2.0% | 5.2% | 16.2% | 17.2% | 14.1% | 18.6% | 12.6% | 9.3% | 5.2% | 0.0% | -1.7% | -5.3% | -0.4% | -19.4% | 7.9% | 3.4% |
| NPR001_41506 | 3.6% | 26.1% | 0.1% | 3.2% | 16.3% | 17.8% | 14.0% | 18.7% | 13.2% | 9.2% | 5.2% | 0.0% | -1.1% | -4.9% | -0.1% | -18.9% | 7.3% | 2.7% |
| NPR001_40819 | 0.4% | 25.8% | -3.0% | -0.1% | 17.0% | 18.6% | 13.8% | 19.1% | 14.1% | 9.1% | 5.1% | 0.0% | -0.2% | -3.9% | 0.4% | -18.2% | 7.5% | 1.7% |
| NPR001_38235 | -1.8% | 25.1% | -5.2% | -2.6% | 15.4% | 18.8% | 13.3% | 19.0% | 14.3% | 8.7% | 4.7% | -0.3% | 0.0% | -3.8% | 0.3% | -18.0% | 6.8% | 0.9% |
| NPR001_34279 | -6.7% | 24.6% | -9.9% | -7.9% | 12.7% | 19.7% | 13.3% | 18.7% | 15.1% | 9.0% | 5.1% | 0.4% | 0.7% | -3.0% | 0.0% | -17.1% | 5.3% | 1.0% |
| NPR001_31927 | -12.8% | 22.7% | -15.9% | -14.5% | 6.9% | 19.4% | 12.1% | 18.8% | 14.8% | 7.9% | 3.9% | -0.3% | 0.4% | -0.8% | 0.0% | -15.6% | 3.4% | -0.7% |
| NPR001_DUM01 | -17.0% | 25.9% | -19.9% | -18.9% | 3.3% | 18.0% | 14.5% | 17.0% | 13.4% | 9.9% | 5.9% | 1.7% | -0.5% | 0.0% | -1.3% | -11.9% | 0.7% | 7.9% |
| NPR001_13848 | -38.6% | -4.0% | -40.4% | -40.4% | -24.9% | -8.3% | -9.4% | -8.3% | -10.4% | -11.5% | 33.1% | 28.1% | 24.5% | 41.2% | 24.0% | 0.0% | -24.2% | -1.1% |

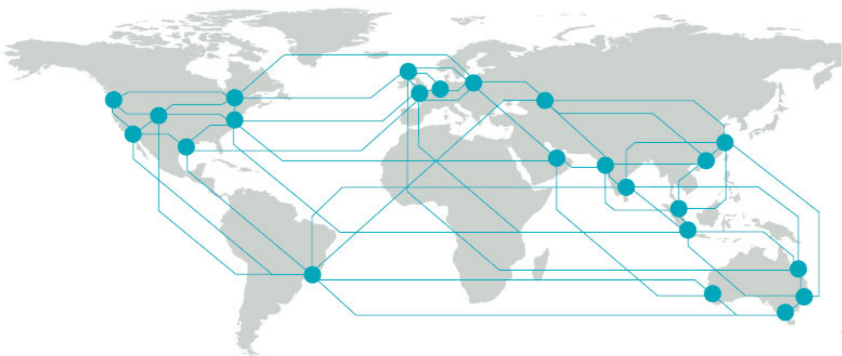
Figure 4.9 Results matrix for the 1% AEP

| | ARFa_180 (TP6) | ARFa_270 (TP9) | ARFb_120 (TP1) | ARFb_120 (TP6) | ARFb_120 (TP8) | ARFc_120 (TP6) | ARFc_270 (TP4) | ARFc_270 (TP8) | ARFc_270 (TP9) | ARFd_270 (TP2) | ARFd_270 (TP7) | ARFd_270 (TP8) | ARFe_270 (TP2) | ARFe_270 (TP7) | ARFe_270 (TP8) | ARFf_270 (TP7) | ARFg_270 (TP1) | ARFg_360 (TP3) | ARFg_360 (TP10) | ARFi_720 (TP16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KOB032_00957 | -3.7% | 0.0% | -7.1% | -8.7% | -7.4% | -16.5% | -16.2% | -5.1% | -9.5% | -11.5% | -14.5% | -9.1% | -15.3% | -18.1% | -13.1% | -22.4% | -21.4% | -22.5% | -20.7% | -32.9% |
| TER010_02189 | 0.0% | 4.7% | 0.3% | -0.5% | -15.1% | -12.7% | -13.3% | -24.0% | -13.1% | -24.9% | -23.5% | -28.2% | -29.5% | -27.2% | -32.8% | -33.3% | -31.7% | -35.3% | -28.4% | -57.8% |
| NPR056_01297 | -3.4% | 17.2% | 3.2% | -1.5% | 0.0% | -33.8% | -34.2% | -12.9% | -9.0% | -26.8% | -38.1% | -20.1% | -36.6% | -44.4% | -30.1% | -50.7% | -48.0% | -46.4% | -46.3% | -54.8% |
| TER012_00000 | -1.6% | 2.5% | 2.8% | 0.0% | -4.1% | -10.2% | -9.5% | -14.2% | -11.3% | -20.1% | -15.0% | -18.7% | -24.3% | -19.1% | -22.7% | -24.3% | -25.1% | -29.5% | -21.8% | -49.2% |
| KOB024_00430 | -14.9% | -11.7% | 0.0% | -4.0% | -3.9% | -13.7% | -22.8% | -21.5% | -22.9% | -27.3% | -24.0% | -25.7% | -30.8% | -27.7% | -29.3% | -32.3% | -33.6% | -38.6% | -32.3% | -51.2% |
| TER001_05833 | 2.4% | 8.4% | 9.6% | 5.2% | 7.3% | -5.4% | 0.0% | 1.0% | -5.3% | -6.4% | -2.0% | -4.2% | -10.9% | -6.8% | -8.8% | -12.7% | -14.9% | -20.8% | -11.1% | -38.7% |
| KOB018_05953 | 9.7% | 17.1% | 13.7% | 8.6% | 11.6% | -13.8% | -13.7% | 8.7% | 0.0% | -1.2% | -3.6% | 2.2% | -7.5% | -12.3% | -3.9% | -21.2% | -20.8% | -22.3% | -19.4% | -33.7% |
| NPR011_DUM01 | 5.1% | 11.1% | 13.1% | 8.8% | 9.4% | -2.2% | 0.4% | 0.0% | -3.2% | -8.1% | -2.6% | -5.2% | -12.5% | -7.3% | -9.8% | -13.2% | -14.9% | -21.0% | -11.8% | -39.5% |
| LAC001_11829 | 0.8% | 10.5% | 15.1% | 11.7% | 10.6% | 0.0% | -6.3% | -2.2% | -3.6% | -10.0% | -6.5% | -7.3% | -14.4% | -11.1% | -11.9% | -16.8% | -16.8% | -21.8% | -14.8% | -38.5% |
| NPR001_DUM03 | 4.3% | 11.7% | 15.0% | 11.4% | 9.3% | 0.0% | -3.0% | -3.1% | -2.8% | -11.3% | -5.6% | -8.2% | -15.6% | -10.2% | -12.7% | -16.0% | -16.9% | -22.2% | -14.1% | -41.5% |
| TER001_04450 | 3.9% | 10.9% | 11.3% | 6.9% | 9.2% | -3.9% | 2.3% | 5.5% | -3.0% | -2.3% | 1.6% | 0.0% | -7.0% | -3.4% | -4.8% | -9.5% | -11.7% | -17.7% | -7.7% | -36.1% |
| KOB018_02518 | 18.2% | 18.2% | 11.1% | 6.7% | 10.2% | -3.5% | -5.7% | 15.9% | -0.2% | 4.6% | 0.0% | 8.5% | -2.6% | -6.1% | 1.1% | -11.6% | -11.1% | -14.3% | -9.4% | -27.5% |
| TER001_01661 | 5.2% | 6.5% | 7.1% | 2.7% | 6.4% | -7.7% | 1.5% | 6.5% | -6.4% | 0.0% | 1.8% | 1.1% | -4.9% | -3.1% | -3.7% | -9.2% | -11.9% | -17.4% | -7.2% | -34.7% |
| NPR001_49127 | 6.2% | 12.2% | 15.4% | 10.7% | 12.9% | -0.5% | 3.5% | 5.5% | -2.0% | -2.3% | 1.9% | 0.0% | -7.0% | -3.0% | -4.8% | -9.1% | -11.5% | -17.6% | -7.6% | -35.6% |
| LAC001_11544 | 13.3% | 23.5% | 28.0% | 24.1% | 23.2% | 11.1% | 5.8% | 10.9% | 7.8% | 1.9% | 5.8% | 5.1% | -3.0% | 0.6% | 0.0% | -5.8% | -6.1% | -11.1% | -2.9% | -28.9% |
| KOB001_10541 | 10.3% | 18.5% | 19.7% | 15.4% | 17.1% | 3.5% | 4.2% | 10.8% | 3.7% | 2.5% | 5.1% | 5.1% | -2.5% | 0.0% | 0.0% | -6.4% | -7.3% | -12.3% | -3.0% | -28.7% |
| KOB001_09533 | 12.5% | 18.5% | 19.5% | 15.0% | 17.5% | 3.2% | 5.7% | 13.5% | 3.9% | 5.1% | 7.2% | 7.7% | 0.0% | 2.0% | 2.5% | -4.5% | -5.5% | -10.8% | -1.1% | -26.9% |
| KOB001_DUM01 | 13.0% | 10.9% | 11.4% | 7.0% | 10.7% | -4.0% | 3.0% | 12.9% | -2.3% | 5.5% | 5.1% | 7.1% | 0.3% | 0.0% | 2.0% | -6.2% | -7.3% | -11.1% | -2.9% | -27.1% |
| LAC001_05600 | 12.8% | 14.1% | 17.7% | 13.0% | 16.8% | 1.5% | 4.7% | 12.9% | 0.2% | 5.2% | 6.1% | 7.2% | 0.0% | 1.0% | 2.0% | -5.4% | -6.5% | -11.5% | -2.1% | -27.2% |
| LAC001_04181 | 12.6% | 12.3% | 15.7% | 11.0% | 15.1% | -0.4% | 4.0% | 12.7% | -1.2% | 5.2% | 5.6% | 6.9% | 0.0% | 0.5% | 1.8% | -5.8% | -7.3% | -11.7% | -2.6% | -27.2% |
| NPR001_DUM02 | 20.7% | 15.0% | 16.7% | 11.9% | 16.4% | 0.5% | 9.8% | 19.9% | 1.9% | 12.6% | 11.9% | 13.9% | 7.1% | 6.6% | 8.5% | 0.0% | -3.4% | -6.0% | 1.6% | -22.7% |
| NPR001_41506 | 21.3% | 13.7% | 14.7% | 10.1% | 14.4% | -1.2% | 10.4% | 20.2% | 1.0% | 13.1% | 11.9% | 14.1% | 7.7% | 6.5% | 8.7% | 0.0% | -4.2% | -5.4% | 0.7% | -22.0% |
| NPR001_40819 | 22.7% | 16.3% | 11.2% | 6.9% | 11.1% | -4.2% | 11.2% | 20.8% | 4.5% | 14.0% | 11.7% | 14.7% | 8.5% | 6.5% | 9.3% | 0.0% | -4.9% | -4.4% | -0.2% | -20.9% |
| NPR001_38235 | 29.3% | 23.8% | 15.2% | 11.1% | 15.0% | -0.5% | 17.0% | 28.0% | 11.1% | 21.2% | 17.8% | 21.6% | 15.4% | 12.3% | 16.0% | 5.6% | 0.0% | 1.4% | 4.6% | -15.5% |
| NPR001_34279 | 25.5% | 24.7% | 7.2% | 3.8% | 7.0% | -7.2% | 14.6% | 25.7% | 11.3% | 20.2% | 15.0% | 19.5% | 14.5% | 9.7% | 13.9% | 3.5% | -3.5% | 0.5% | 0.0% | -14.8% |
| NPR001_31927 | 17.6% | 24.0% | -6.2% | -8.0% | -6.4% | -17.9% | 10.1% | 21.9% | 10.2% | 16.3% | 9.3% | 16.0% | 10.9% | 4.7% | 10.6% | -0.8% | -4.8% | 0.0% | -4.1% | -14.3% |
| NPR001_DUM01 | 12.9% | 22.0% | -11.6% | -13.2% | -11.8% | -22.6% | 13.8% | 19.4% | 8.2% | 14.5% | 11.5% | 13.6% | 9.1% | 6.7% | 8.3% | 1.0% | -7.1% | 0.0% | -7.2% | -10.1% |
| NPR001_13848 | -20.3% | -2.5% | -37.0% | -37.2% | -37.2% | -43.2% | -11.5% | -9.6% | -11.8% | -13.0% | -14.3% | -12.9% | -16.0% | -17.2% | -16.0% | -20.6% | -23.6% | -8.2% | -9.5% | 0.0% |

Figure 4.10 Results matrix for the 0.1% AEP

| | ARFa_180 (TP8) | ARFa_270 (TP9) | ARFb_90 (TP9) | ARFb_120 (TP6) | ARFb_120 (TP8) | ARFc_270 (TP2) | ARFc_120 (TP6) | ARFc_120 (TP8) | ARFc_270 (TP4) | ARFc_270 (TP8) | ARFd_270 (TP2) | ARFd_270 (TP4) | ARFd_270 (TP7) | ARFd_270 (TP8) | ARFe_270 (TP2) | ARFe_120 (TP8) | ARFe_270 (TP7) | ARFf_270 (TP7) | ARFg_360 (TP3) | ARFi_720 (TP20) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KOB032_00957 | -3.1% | 0.0% | -15.5% | -8.9% | -8.1% | -8.3% | -16.0% | -15.0% | -15.9% | -6.0% | -11.7% | -19.2% | -14.6% | -9.7% | -15.1% | -22.9% | -18.3% | -23.1% | -22.0% | -37.1% |
| TER010_02189 | 0.0% | 4.8% | 6.6% | 1.1% | -14.7% | -24.1% | -13.2% | -24.9% | -12.8% | -27.6% | -28.2% | -19.6% | -27.7% | -31.0% | -31.8% | -31.3% | -30.6% | -34.9% | -37.7% | -61.5% |
| NPR056_01297 | 2.5% | 3.6% | -17.8% | 4.3% | 0.0% | -25.6% | -21.6% | -20.9% | -38.9% | -21.0% | -31.0% | -43.2% | -35.3% | -27.3% | -35.3% | -46.1% | -44.8% | -53.8% | -49.6% | -64.0% |
| TER012_00000 | -2.2% | 3.1% | 1.3% | 0.0% | -4.4% | -16.4% | -10.9% | -14.1% | -9.8% | -15.6% | -21.2% | -15.0% | -16.7% | -20.3% | -25.6% | -23.0% | -21.0% | -26.5% | -31.6% | -53.2% |
| KOB024_00430 | -12.0% | -13.1% | 0.0% | -5.5% | -5.8% | -26.2% | -15.7% | -15.6% | -24.6% | -24.2% | -30.0% | -28.8% | -26.9% | -28.3% | -33.6% | -24.6% | -30.6% | -35.4% | -41.4% | -55.9% |
| TER001_05833 | 3.3% | 9.5% | 3.2% | 6.2% | 8.1% | -2.5% | -5.3% | -3.3% | 0.2% | 0.0% | -7.7% | -5.4% | -3.4% | -5.4% | -12.3% | -13.8% | -8.3% | -14.6% | -22.5% | -43.3% |
| KOB018_05953 | 12.2% | 15.7% | -0.7% | 15.7% | 16.6% | 0.0% | -6.5% | -4.1% | -11.0% | 4.3% | -5.6% | -17.9% | -5.3% | -2.5% | -11.0% | -22.9% | -11.9% | -20.6% | -23.4% | -42.5% |
| NPR011_DUM01 | 5.6% | 11.7% | 8.6% | 9.3% | 9.6% | -4.3% | -2.5% | -1.9% | 0.0% | -1.5% | -9.5% | -5.6% | -4.5% | -6.9% | -14.3% | -12.4% | -9.3% | -15.6% | -23.1% | -44.2% |
| LAC001_11829 | 8.5% | 11.7% | 13.8% | 13.5% | 12.0% | -6.0% | 0.8% | 0.0% | -6.1% | -2.9% | -11.0% | -11.3% | -7.6% | -8.3% | -15.5% | -11.0% | -12.3% | -18.5% | -23.2% | -42.9% |
| NPR001_DUM03 | 8.0% | 12.8% | 12.4% | 12.3% | 9.8% | -7.8% | 0.0% | -1.6% | -3.0% | -4.1% | -12.6% | -8.4% | -7.1% | -9.4% | -17.0% | -12.1% | -11.8% | -18.0% | -24.0% | -45.9% |
| TER001_04450 | 7.3% | 13.1% | 3.9% | 9.4% | 11.5% | 3.0% | -2.4% | -0.3% | 3.8% | 5.7% | -2.4% | -2.0% | 1.5% | 0.0% | -7.3% | -11.3% | -3.7% | -10.3% | -18.4% | -40.2% |
| KOB018_02518 | 15.0% | 16.6% | -2.6% | 12.8% | 16.2% | 9.8% | -7.0% | -3.8% | -5.7% | 13.5% | 3.1% | -11.1% | 0.0% | 6.3% | -3.3% | -14.9% | -6.8% | -15.9% | -16.8% | -35.8% |
| TER001_01661 | 3.8% | 8.5% | -2.4% | 5.0% | 9.0% | 5.6% | -6.0% | -2.8% | 2.7% | 6.8% | 0.0% | -2.8% | 1.7% | 1.1% | -5.1% | -13.6% | -3.4% | -10.0% | -17.9% | -39.2% |
| NPR001_49127 | 10.1% | 15.7% | 11.4% | 14.3% | 16.3% | 3.9% | 1.9% | 3.9% | 5.9% | 6.6% | -1.6% | 0.0% | 2.7% | 0.9% | -6.5% | -7.4% | -2.5% | -9.2% | -17.6% | -39.1% |
| LAC001_11544 | 22.0% | 26.1% | 26.9% | 27.0% | 25.9% | 7.5% | 12.9% | 12.3% | 7.2% | 11.2% | 1.9% | 1.2% | 5.7% | 5.1% | -3.3% | 0.0% | 0.2% | -6.8% | -11.9% | -33.5% |
| KOB001_10541 | 16.0% | 21.4% | 15.1% | 18.6% | 20.1% | 8.5% | 5.5% | 7.1% | 6.0% | 11.5% | 2.8% | 0.1% | 5.4% | 5.5% | -2.4% | -4.8% | 0.0% | -6.9% | -12.8% | -33.2% |
| KOB001_09533 | 13.9% | 18.9% | 11.0% | 15.9% | 18.2% | 9.1% | 3.1% | 5.3% | 5.4% | 12.0% | 3.4% | -0.4% | 5.4% | 5.9% | -1.9% | -6.5% | 0.0% | -6.9% | -13.0% | -33.0% |
| KOB001_DUM01 | 9.6% | 13.2% | 2.7% | 9.8% | 13.7% | 11.9% | -2.2% | 1.0% | 4.6% | 13.5% | 5.9% | -1.0% | 5.3% | 7.5% | 0.4% | -10.6% | 0.0% | -6.8% | -11.7% | -32.3% |
| LAC001_05600 | 13.2% | 16.5% | 12.2% | 16.1% | 19.9% | 11.3% | 3.3% | 6.7% | 6.2% | 13.5% | 5.4% | 0.5% | 6.2% | 7.4% | 0.0% | -5.4% | 0.9% | -6.1% | -12.1% | -32.1% |
| LAC001_04181 | 11.9% | 14.6% | 9.2% | 14.0% | 18.2% | 11.3% | 1.5% | 5.1% | 5.4% | 13.2% | 5.4% | -0.2% | 5.7% | 7.2% | 0.0% | -6.8% | 0.4% | -6.5% | -12.3% | -32.2% |
| NPR001_DUM02 | 16.7% | 17.9% | 6.5% | 15.9% | 20.6% | 20.1% | 3.1% | 7.0% | 11.8% | 21.3% | 13.7% | 6.1% | 12.8% | 14.9% | 7.8% | -5.3% | 7.2% | 0.0% | -5.9% | -27.9% |
| NPR001_41506 | 15.9% | 16.4% | 3.8% | 14.0% | 18.5% | 20.5% | 1.4% | 5.1% | 12.3% | 21.5% | 14.2% | 6.6% | 12.8% | 15.1% | 8.4% | -7.1% | 7.2% | 0.0% | -5.4% | -27.5% |
| NPR001_40819 | 17.5% | 18.1% | -0.3% | 10.6% | 15.1% | 21.3% | -1.7% | 2.0% | 13.0% | 22.1% | 15.0% | 7.3% | 12.6% | 15.7% | 9.1% | -10.0% | 7.1% | 0.0% | -4.4% | -26.8% |
| NPR001_38235 | 22.2% | 24.1% | 0.8% | 13.5% | 17.7% | 27.2% | 0.8% | 4.1% | 17.4% | 27.6% | 20.5% | 11.5% | 17.2% | 21.0% | 14.5% | -8.1% | 11.4% | 4.1% | 0.0% | -23.0% |
| NPR001_34279 | 20.1% | 26.4% | -7.1% | 6.9% | 10.4% | 27.0% | -5.2% | -2.5% | 15.6% | 26.4% | 20.5% | 10.0% | 15.1% | 19.9% | 14.5% | -14.1% | 9.6% | 2.8% | 0.0% | -22.3% |
| NPR001_31927 | 16.3% | 26.3% | -20.8% | -5.2% | -3.5% | 23.4% | -15.7% | -14.3% | 11.1% | 23.2% | 17.3% | 6.3% | 10.1% | 17.1% | 11.6% | -24.4% | 5.1% | -1.1% | 0.0% | -21.9% |
| NPR001_DUM01 | 11.9% | 24.2% | -26.3% | -10.7% | -9.3% | 21.8% | -20.7% | -19.5% | 15.1% | 20.8% | 15.6% | 9.7% | 12.3% | 14.7% | 9.9% | -29.2% | 7.1% | 0.7% | 0.0% | -18.9% |
| NPR001_13848 | -20.7% | -1.9% | -47.8% | -37.5% | -37.5% | -10.0% | -42.8% | -42.7% | -12.0% | -10.0% | -13.8% | -15.5% | -15.3% | -13.7% | -17.1% | -48.6% | -18.4% | -22.0% | -9.0% | 0.0% |

Figure 4.11 Results matrix for the 0.05% AEP



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