Hydrography Landuse and Hydrology Update 2019
Moreton Bay Regional Council
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# Regional Flood Database

## Hydrography Landuse and Hydrology Update 2019

Revision 2 – 23-Dec-2020
Prepared for – Moreton Bay Regional Council – ABN: 92 967 232 136

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Hydrography Landuse and Hydrology Update 2019

Client: Moreton Bay Regional Council

ABN: 92 967 232 136

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# Executive Summary

Moreton Bay Regional Council (MBRC) maintain a Regional Flood Database (RFD) which provides access to flooding information across the entire Local Government Area (LGA) boundary. Recent updates to Australian Rainfall and Runoff (ARR), new LiDAR and Aerial Imagery plus advances in modelling software means the time is right for MBRC to undertake a major RFD update. MBRC have commenced this process across 3 stages, with Stage 1 (ARR 2019 pilot study) and Stage 2 (hydrography, landuse and hydrology update) to feed into Stage 3 (RFD major update).

AECOM Australia Pty Ltd (AECOM) have been commissioned by MBRC to undertake works related to Stage 2 of the RFD – including updated hydraulic roughness, fraction impervious and catchment delineation feeding into updated WBNM hydrologic models. This report outlines the processes and findings of following tasks undertaken in Stage 2 of the MBRC RFD update:

- 2019 Landuse Condition Layers
- 2019 Pervious-Impervious Raster
- 2019 Hydrography Update
- 2019 Conditions WBNM Modelling

**<u>2019 Landuse Condition Layers</u>**

Landuse condition layers were updated using the 2019 LAS and aerial imagery datasets. A Random Forest algorithm (machine learning) was used to predict the landuse classification based on the relative height (z) and imagery (red-green-blue bands) at a 1m resolution. This output was post-processed to remove noise and liken the output to a traditional approach. Outlines of roads, buildings and waterbodies were further improved using feature extraction from the LAS dataset. Density of understory vegetation (critical for hydraulic modelling) was estimated using a data science approach which produced comparative density classes (low, medium and high).

**<u>2019 Pervious-Impervious Raster</u>**

Each landuse category was assigned a fraction impervious and used to create updated percent-impervious rasters across the LGA. These rasters were used to update minor catchment impervious parameters using Zonal Statistics. Comparison of the before-after impervious parameters revealed:

- The majority of increased imperviousness occurred within the minor basins of BCR, LPH, BRI, BCC and RED.
- Minor basins which encompass large water storages (e.g. UPR, SRN), generally see a decrease in fraction impervious, indicating that the time at which this project was undertaken may be been drier than that used for the previous data.
- The overall impervious area increased by more than 3,100ha across the full LGA.

**<u>2019 Hydrography Update</u>**

Hydrography layers (minor catchments, reaches and junctions) were also refined where development had occurred or more detail was needed to support subsequent modelling phases. The majority of updates were made within the BCR, LPH and BCC catchments where significant development has taken place in recent times.

Stream lag factors associated with each defined minor catchment were also re-estimated using Council's stormwater infrastructure databases. This exercise resulted in significant changes to modelled lag factors which will directly influence the 2019 Conditions WBNM Modelling.

**<u>2019 Conditions WBNM Modelling</u>**

The 2019 package of refinements and revised parameters were applied to updated WBNM models and compared to previous estimates of peak flow and volume to understand the potential changes in predicted flood behaviour. Generally, increases in fraction impervious, minor catchment refinements and revised stream lag factors resulted in changes to peak flow and volume in urban areas (particularly dense urban areas) and minor changes in undeveloped areas.

# 1.0 Introduction

## 1.1 Project Background

Moreton Bay Regional Council (MBRC) have developed an extensive and detailed Regional Flood Database (RFD), covering fourteen basins within the MBRC local government area. Developed in 2009 and updated in 2014 / 2016, MBRC's region wide library comprises coupled WBNM hydrologic and TUFLOW hydraulic models, which are primarily based on Australian Rainfall and Runoff 1987 (ARR87).

Release of the 2019 update to ARR (ARR19), along with LiDAR and Aerial Imagery collected over 2018-2019 across the region, means the time is right for MBRC to undertake a major update to their RFD. MBRC have commenced the RFD update across three stages, as shown in Figure 1 below.

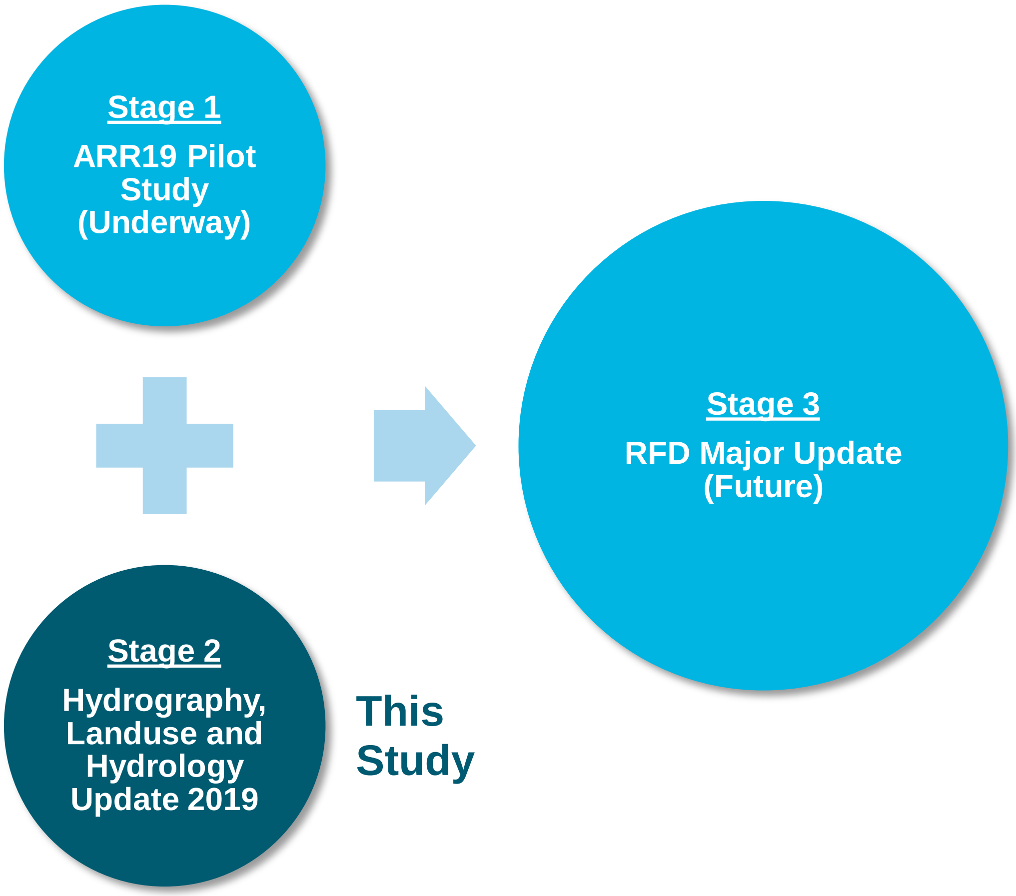



**Figure 1 RFD Update Project Stages**

In December 2019 MBRC engaged AECOM Australia Pty Ltd (AECOM) to undertake the RFD Hydrography, Landuse and Hydrology Update (Stage 2). The key objective of Stage 2 (this study) is to refine landuse, hydrography and hydrology inputs to facilitate update of MBRCs WBNM and TUFLOW models to 2019 conditions. Updates to the TUFLOW hydraulic models completed in Stage 3 utilising inputs from Stages 1 and 2.

## 1.2 Objectives

The key objectives of the Stage 2 works include:

- **Updated Hydraulic Roughness** – accurate representation of ground conditions and associated runoff characteristics is essential in preparing high quality hydrologic and hydraulic models (referred to in this report as the *2019 Landuse Condition Layers* task).
- **Updated Fraction Impervious** – identification of imperviousness facilitates translation of rainfall to runoff across differing ground conditions (referred to in this report as the *2019 Pervious-Impervious Raster* task).
- **Updated Catchment Delineation** – it is important to ensure the full extent of each catchment is included in the hydrologic and hydraulic models, to more accurately estimate discharge (referred to in this report as the *2019 Hydrography Update* task).
- **Preparation of New WBNM Models** – inputs from the above tasks will allow updates to existing and creation of new WBNM hydrologic models across the MBRC local government area (referred to in this report as the *2019 Conditions WBNM Modelling* task)

## 1.3 Scope

The subsequent sections outline the scope of works associated with each of the project tasks identified above.

**2019 Landuse Condition Layers**

The scope of the *2019 Landuse Condition Layers* task was to develop a definitive 'existing catchment' land use mapping dataset, for use in hydrologic and hydraulic modelling, including both catchment impervious cover and surface roughness zones. The extent of coverage included all minor basins within the MBRC Local Government Area (LGA) (see Figure 2) and extending into neighbouring LGA's where appropriate.

Areas of varying landuse are required to be delineated in the landuse conditions layers for use in the hydraulic modelling. Each surface type within the catchment can later be assigned a roughness value (Manning's 'n') that is interpreted by the hydraulic model during computation.

**2019 Pervious-Impervious Raster**

Following the completion of the 2019 Landuse Conditions Layers task, the 2019 Pervious-Impervious Raster was generated by identifying the impervious cover proportion within each basin and minor catchment. Estimates of imperious cover are used in the hydrologic model and relate to how rainfall is converted to runoff. These impervious values are applied as an attribute to the delineated minor catchment for interpretation by the model.

**2019 Hydrography Update**

Hydrography was updated using the 2019 LiDAR dataset, Council's stormwater asset database and selected minor catchments flagged by Council. Together with each minor catchment, stream centrelines (reaches) and junctions with minor catchment boundaries were also updated. These updates factored in landscape changes (i.e. development) and the presence of hydraulic controls, such as embankments and cross-drainage structures. Council's established naming convention was used, with some minor adjustments, to ensure topological connectivity was maintained.

**2019 Conditions WBNM Modelling**

Using the Percent-Impervious Rasters (PIR's), updated catchment and landuse information, a library of 2019 Conditions WBNM models was established for the region. Following refinement of the hydrography, each minor catchment (used for WBNM) was assigned a revised fraction impervious and stream lag factor.

The following minor basins were also combined into a single WBNM model:

- Burpengary Creek (BUR) & Caboolture River (CAB) → Burpengary Creek and Caboolture River (BCR);
- Lower Pine River (LPR) & Hays Inlet (HAY) → Lower Pine River and Hays Inlet (LPH); and
- Stanley River (STA) & Neurum Creek (NEU) → Stanley River and Neurum Creek (SRN).

The adopted minor basins for this project are presented in Figure 2.

## 1.4 Limitations

The following limitations apply to this study and associated deliverables:

- Any use by others of this document and associated deliverables (digital layers), or any reliance on or decision to be made based on it, is the responsibility of such third parties. AECOM accepts no responsibility for damages, if any, suffered by any third party as a result of decisions or actions made based on this document or data. Deliverables include:
  - 2019 Landuse Conditions Layer Package.
  - 2019 Percent-Impervious Raster and Infographics.
  - 2019 Hydrography Update (Minor Catchments, Reaches and Junctions).
  - 2019 WBNM Conditions WBNM Models.
  - This Report.
- Where information has been supplied by Council or other external sources, the information has been assumed correct and accurate unless stated otherwise. No responsibility is accepted by AECOM for incorrect or inaccurate information supplied by others.
- Deliverables created within this project are contingent on the timestamp, currency and quality of input datasets. These deliverables represent a specific period in time, based on the date of capture for Laser Aerial Scanning (LAS) and aerial imagery datasets.
- Given the static nature of layers generated in this project, impacts from seasonal variance should be assessed in subsequent phases to understand the sensitivity of model behaviour between seasons (i.e. wet / dry seasons), crop rotations and the like.
- Layers created within this project are specific to the local region. Due to the unique characteristics of each region it is neither practical nor possible to anticipate subsequent challenges associated with use of these layers. Implementation within varying modelling platforms and technologic advancements may require unique schematisation of digital layers on an as-needed basis.
- This data cannot be relied on for any use other than inputs to hydrologic and hydraulic modelling and may be subject to change during subsequent modelling phases.

## 1.5 Report Structure

The structure of this report is as follows:

- Section 2.0 outlines the available data at the commencement of the project and the limitations that applied to each dataset used.
- Section 3.0 describes the work undertaken as part of *2019 Landuse Condition Layers*.
- Section 4.0 describes the work undertaken as part of *2019 Pervious-Impervious Raster*.
- Section 5.0 describes the work undertaken as part of *2019 Hydrography Update*.
- Section 6.0 describes the work undertaken as part of *2019 Conditions WBNM Modelling*.
- Section 7.0 provides the conclusions drawn from the work undertaken as well as recommendations going forward into future phases.

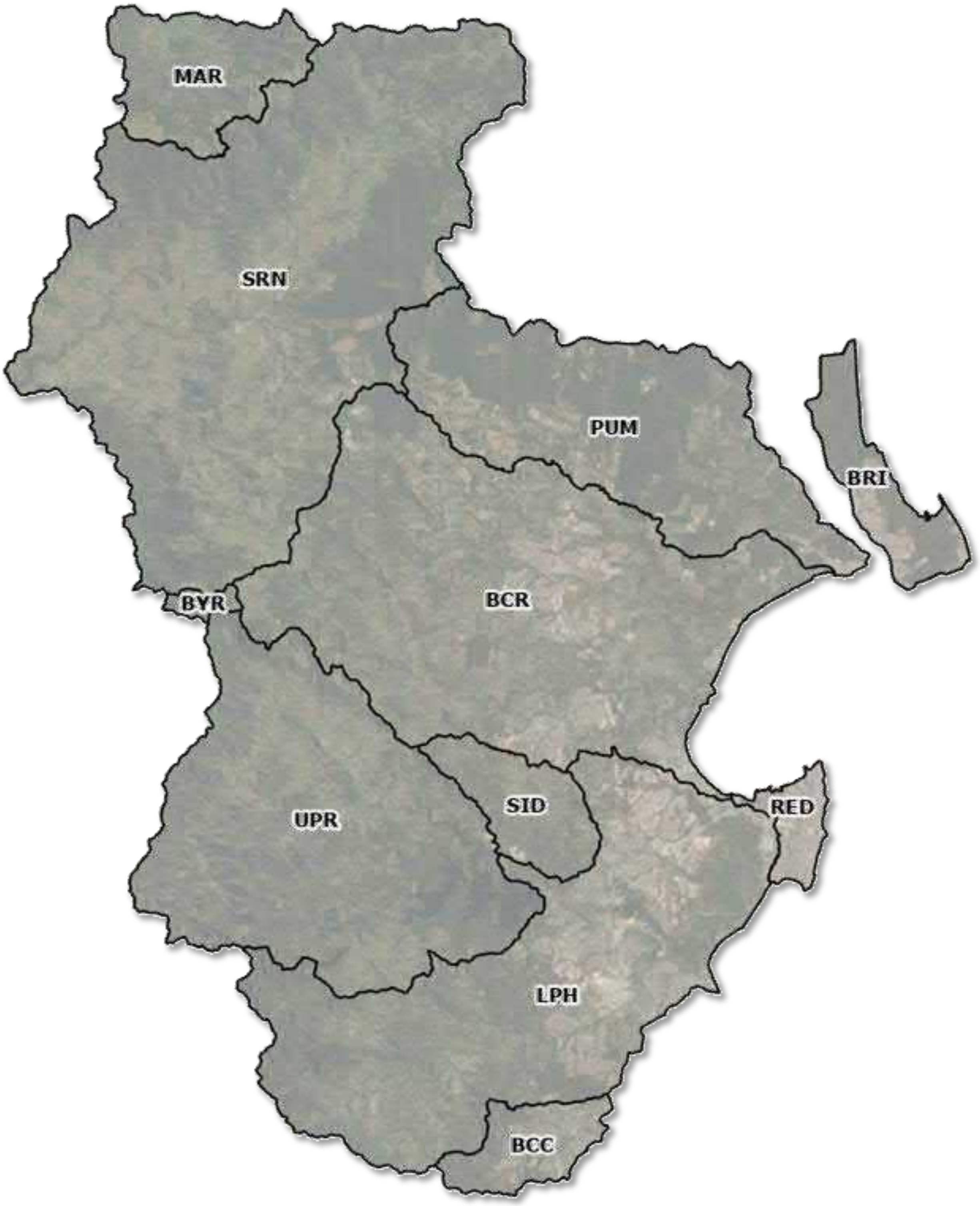



**Figure 2 LGA Minor Basins Overview**

# 2.0 Available Data

## 2.1 Overview

MBRC provided AECOM with several datasets and databases, including LiDAR, aerial imagery, cadastral data, land use classifications and the like. Detailed information relating to each of the supplied datasets, as well as limitations in application of data for this project have been listed in the subsequent sections below.

## 2.2 2019 LiDAR & Aerial Imagery

Full waveform LiDAR was collected on 25/11/2018 through 26/05/2019 by RPS, at low altitude to obtain a density of 4 points per square metre. This data capture project covered the vast majority of the MBRC LGA. Data within tidally influenced areas were captured within 2 hours of low tide to ensure pickup of topographic features within the inter-tidal zone. The vertical accuracy of the LiDAR data was validated against ground control points collected by RPS surveyors which quantified a root-mean-square-error of 141mm and standard deviation of 111mm. LiDAR data was also Level 1 semi-automatically classified. LiDAR was supplied in both raw LAS (tiles) and filtered Digital Elevation Model (DEM) (tiles) formats.

Aerial Imagery was captured at the time of LiDAR capture with a similar level of accuracy to the LiDAR. RPS noted that as photographic control was not explicitly established as a part of LiDAR capture, imagery cannot be categorically determined as being either more or less accurate than the LiDAR capture. Therefore, the stated accuracy of the aerial photography is +/- 80cm horizontally. Aerial imagery was supplied as JP2 tiles.

## 2.3 Previous Datasets

Council included the following 2009 datasets to facilitate comparative analysis for identification of infill development and other changes:

- 2009 LiDAR as a DEM (tiles).
- 2009 PIR Rasters for each minor basin (e.g. RED).
- 2014 LAS for MAR and STA basins.

It was noted that the 2019 LiDAR project did not capture a portion of STA or MAR basin headwaters. In order to prepare a complete dataset, 2014 LAS was adopted where 2019 data was not available.

## 2.4 GIS Layers

Council supplied latest versions as at 2019 of the following GIS databases:

- Bikeways / Pathways as polygons.
- Stormwater assets as points, polylines and polygons.
- Canals as polylines and polygons.
- Carparks as polygons.
- Road edges as polylines and reserves as polygons.
- MBRC Planning Zones as polygons.

## 2.5 Current Landuse Condition Layers

MBRC have a number of spatially varying landuse conditions layers across their LGA. Although quite detailed and incorporating a broad range of differing classifications, the land use layers do have some limitations, including:

- Unclassified areas within the major basins.

- Mismatch between the latest aerial imagery and landuse layers.
- Missing features such as roads, buildings & carparks.

As this dataset was developed as part of the original RFD project in 2009-2012 using 2009 data and updated manually between 2014-16 within the PMF extent, it is expected that changes to the landuse since these works would not be captured within the dataset.

The image below shows a preview of the previous landuse conditions layer within the Brisbane Coastal Creeks (BCC) basin.

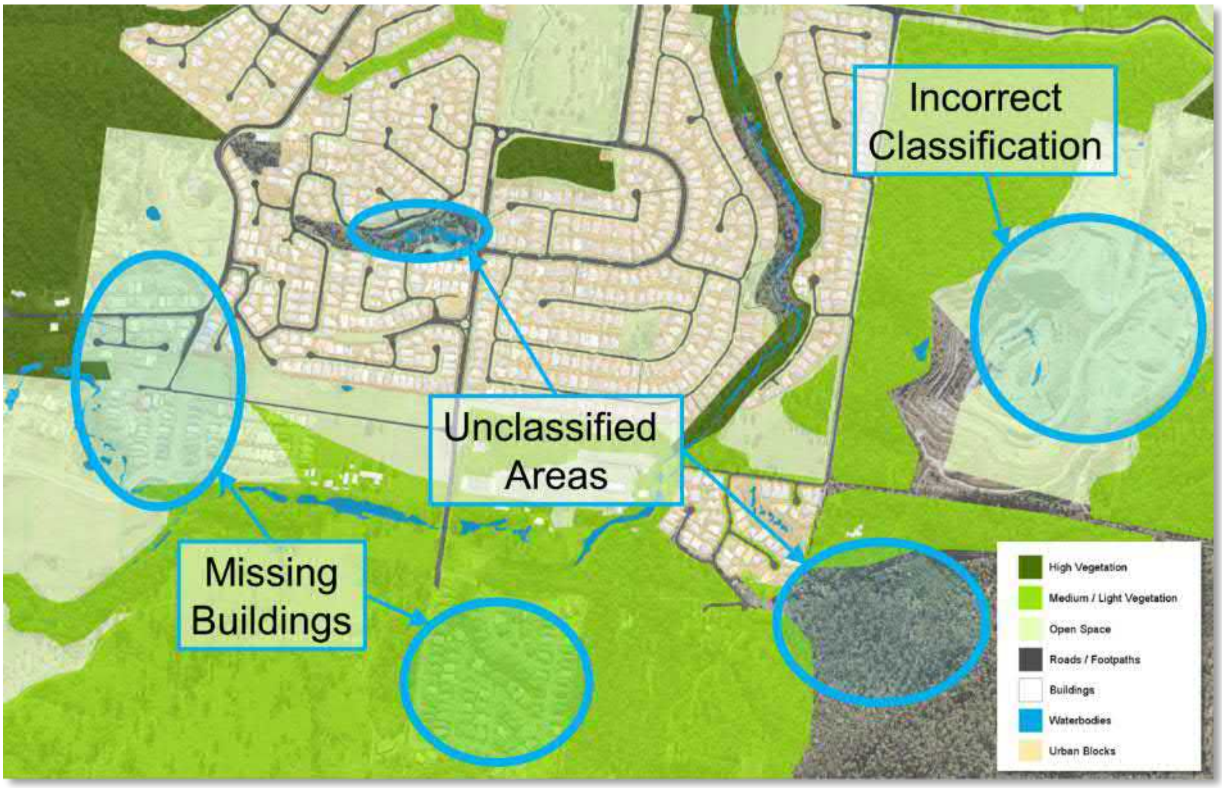



**Figure 3 Previous Landuse Conditions Layer (2009 Data)**

## 2.6 Hydrography

Hydrography across the LGA was supplied as a combined database of:

- Stream junctions as points (updated 2014-15).
- Stream reaches as polylines (updated 2014-15).
- Minor catchments as polygons (updated 2014-15).

Hydrographic Areas of Interest were also supplied to highlight areas of focus based on Council's local knowledge of changes in landuse or hydraulic features.

## 2.7 Hydrologic / Hydraulic Models

WBNM models updated in 2014-15 for each minor basin were supplied, complete with IFD files and design event results (5%, 1% and 0.1% Annual Exceedance Probability, AEP) using WBNM 2010. Council also supplied select hydraulic files, including TUFLOW code boundaries, hydraulic structures and peak flood height rasters for the 1% AEP event.

# 3.0 2019 Landuse Condition Layers

## 3.1 Overview

Developing the 2019 Landuse Condition Layers included a range of methods to identify landuse conditions as accurately and efficiently as possible. These methods included:

- Overlay of available datasets to identify prominent changes in landuse and distribution.
- Using machine learning (ML) within a GIS interface to rapidly classify landuse using the latest imagery. Depending on the quality of the model training, the outputs can then be used to:
  - Automatically re-classify areas where landuse has been modified.
  - Use the trained model to inform manual assignment of landuse classes and distributions.

The following sections provide details on the methodology and results for developing the 2019 Landuse Condition Layers.

## 3.2 Data Collection and Gap Analysis

This initial phase of the 2019 Landuse Condition Layers task collated all available data, assessed the quality and completeness of data and addressed any data gaps. Significant gaps in information were discussed with Council and where possible, solutions to address the gap were proposed.

Based on review of the available information, it was determined that 2019 LiDAR was of satisfactory quality for use in this assessment. A small portion of the STA and MAR basin headwaters were noted to be missing from the 2019 dataset. In order to prepare a complete dataset, 2014 LAS was adopted where 2019 LAS was not available.

2019 aerial imagery varied in useability for the assessment due to the following challenges:

- Clouds.
- Shadows (from clouds or on-ground features).
- Differing times of day, which influences shadows and colour band combinations (RGB).
- Varying tidal levels, creating a mismatched coastal profile.
- ‘Holes’ between tiles.

Due to these limitations, the project team agreed the 2019 aerial imagery cannot be the primary training dataset due to the likelihood of increased confusion and misclassification in prediction. As a result, the 2019 classified LAS data was adopted as the primary training dataset and supported with 2019 imagery as a secondary training dataset.

## 3.3 Proof of Concept

In order to demonstrate an appropriate methodology, the project team commenced a proof of concept process. This component applied initial findings from research and development to local catchments at six locations presented below in Table 2. This process was used to evaluate the effectiveness of a machine learning approach to landuse delineation and was agreed with Council prior to commencing LGA-scale landuse classification in Section 3.4.

### 3.3.1 Machine Learning Techniques

The first step in determining the most appropriate methodology to complete the landuse conditions task was testing the suitability of various data inputs, machine learning algorithms and parameter settings within pilot areas. Table 1 presents a summary of the learning types and classification types applied during assessment of the pilot areas.

**Table 1 Summary of Machine Learning Techniques**

| Training Approach | |
|---|---|
| Supervised | Requires the user to provide samples of what the classification looks like to the machine pre-possessing. |
| Unsupervised | The machine looks at the data and tries to cluster together data into a specified number of classes. These classes are made based on the statistical grouping – not user input. |
| **Classification Algorithm** | |
| **Random Forest (selected for this project)** | • Supervised<br>• Creates a 'tree' of true or false questions that it asks to separate data into different categories. This is then expanded outwards into a collection of trees with a collection of questions.<br>• Classifies data based on probability it belongs to a given class<br>• Suited for circumstances that have a multi-class output<br>• Typically, very easy to interpret why classifications are made<br>• Very fast classification method<br>• Resistant to overfitting (not able to understand new data) due to considering different trees of decisions |
| Support Vector Method | • Supervised<br>• Creates a 'border' between the specified categories and classifies points based on the distance from this border<br>• Good for classification of data with clear differences that allows a border to be drawn<br>• Poor defendability and precision where class boundaries are not clear.<br>• Takes longer and is more difficult to interpret decisions in complex datasets |
| ISO Cluster | • Unsupervised<br>• Groups data into a specified number of categories based off clustering of data<br>• Cannot specifically target certain categorisation |

### 3.3.2 Pilot Area Testing

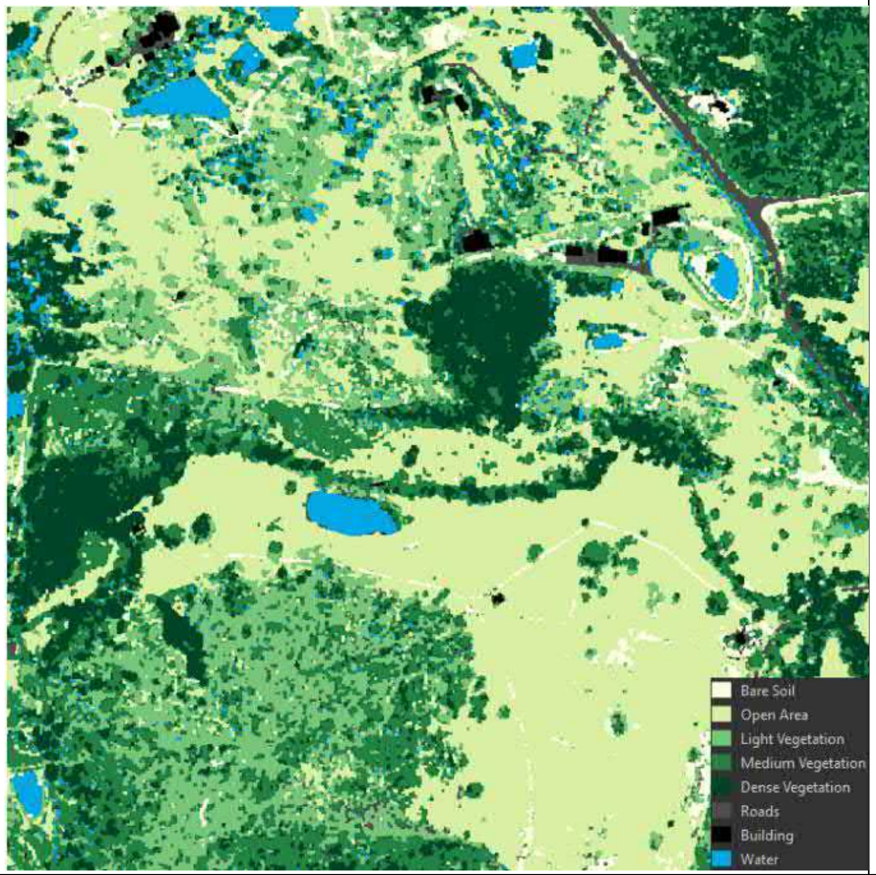
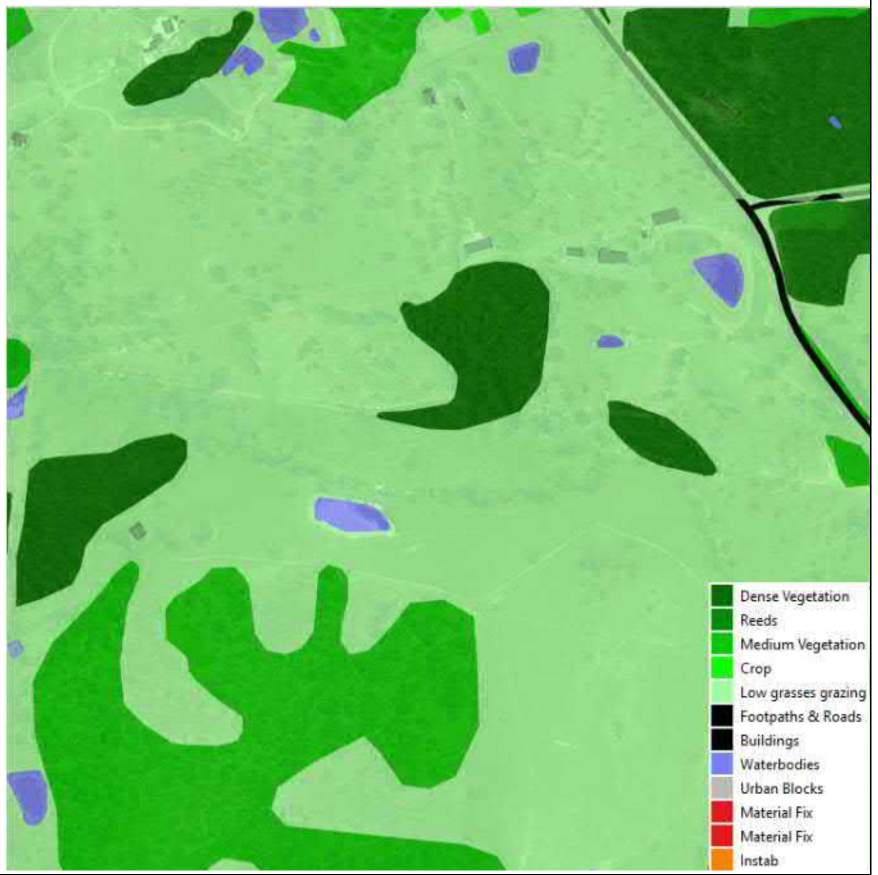
Six pilot study areas were selected to test the suitability of machine learning techniques identified in Section 3.3.1. These areas measured 1km$^2$ each and were selected to represent the varying landuse and terrain across the LGA. Based on initial testing, troubleshooting and refinement, several conclusions were reached:

- Training must use high-quality samples that avoid blending of class boundaries.
- Due to the challenges associated with aerial imagery dataset quality, shadows present a significant limitation and must be overcome by combining aerial and topographic datasets in training.
- Topographic information must be applied using a relative scale.
- The Random Trees algorithm is the most suitable (precision and performance) for classifying landuse. This finding is consistent with findings during external research and development.
- A 1m resolution provides a reasonable balance between client end-use and scalable performance.
- Generally, 50 samples provide a reasonable dataset with which to train the algorithm.

Each pilot area was classified using a trained random forest algorithm. Raw results from this process were mapped to support ground truthing and are presented in Table 2.

**Table 2 Machine Learning Pilot Areas**

| Pilot | Imagery | Machine Learning Predicted Classification | Previous Classification |
|---|---|---|---|
| **Urban Area**<br>Mixture of roads, riparian corridor and residential landuses. |  |  |  |
| **Coastal Area**<br>Mixture of roads, waterbodies and residential landuses. |  |  |  |

<table>
<tr><th>Pilot</th><th>Imagery</th><th>Machine Learning Predicted Classification</th><th>Previous Classification</th></tr>
<tr><td>Rural Area<br>Mixture of tree clusters, open space and small amount of infrastructure.</td><td></td><td>
</td><td>
</td></tr>
<tr><td>Commercial / Industrial Area<br>Large buildings, roads and open space.</td><td></td><td>
</td><td>
</td></tr>
</table>

<table>
<tr><th>Pilot</th><th>Imagery</th><th>Machine Learning Predicted Classification</th><th>Previous Classification</th></tr>
<tr><td>Highlands<br>Mixture of tree clusters and open space with highly variable topography.</td><td></td><td>
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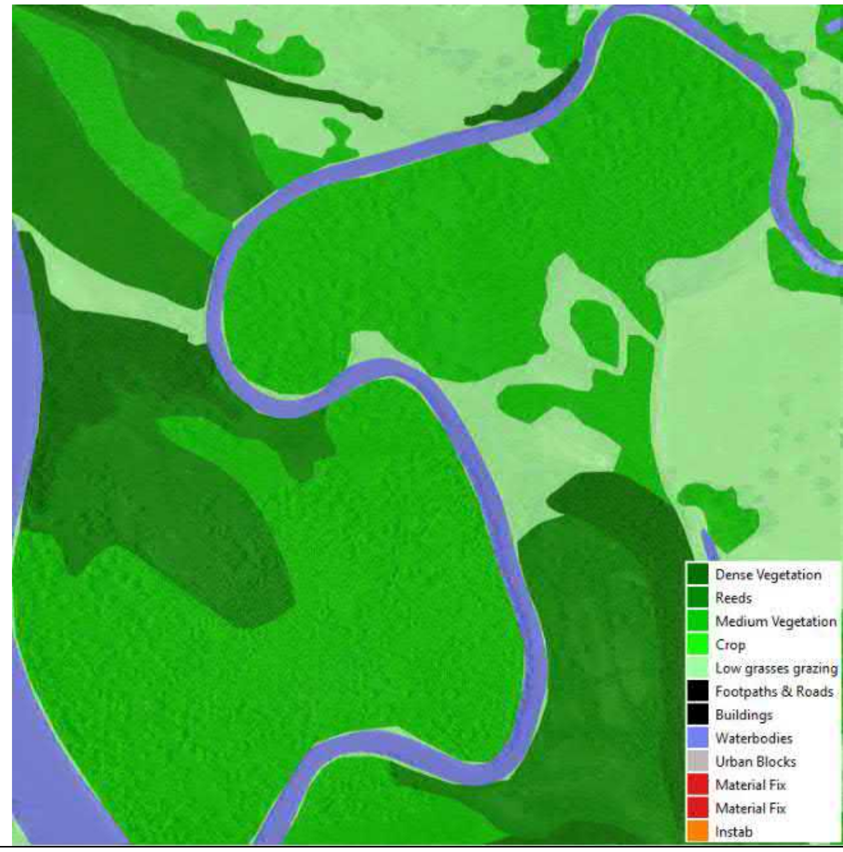
</td></tr>
<tr><td>Mangroves<br>Mixture of various vegetation types and open space.</td><td></td><td>
</td><td>
</td></tr>
</table>

### 3.3.3 Ground Truthing

Following completion of the proof of concept, a site visit to ground truth findings of the assessment was undertaken by MBRC and AECOM staff. Sites for inspection were selected to provide a representation of the different landuse attributes across the study area, as well as those areas that have proven difficult to identify via desktop means. The predicted landuse at each site was constructively reviewed to identify limitations in the approach and opportunities for improvement.

Collaborative review of the findings between site visits by MBRC and AECOM concluded with the following outcomes:

- The automated approach provides improved classification of landuse in all pilot areas compared to traditional approaches. However, some layers are 'noisy' and will require cleaning (e.g. roads, buildings, waterbodies).
- Open Space aligns well with maintained grass and cleared areas.
- Vegetation extents are well defined and consistent with findings on site.
- Vegetation canopy height does not always correlate with understory density and will be difficult to defend when assigning hydraulic roughness in subsequent modelling phases (refer Section 3.4.4 below for further discussion).

## 3.4 Final Adopted Methodology

Based on the findings of collaborative discussions and site visits between AECOM and MBRC, the following methodology was adopted to generate the 2019 Landuse Conditions Layers.

### 3.4.1 Previous Layers

Council's previous landuse and GIS databases were reviewed for quality datasets suitable to layer into the automatically generated layers. This approach ensures the best available data is built into the deliverable. In the case on finer layers, such as pathways, this improved the overall quality of the final database. The following datasets were factored into the layer package:

- Sealed road outlines.
- Bikeways / pathways.
- Facilities (e.g. sports facilities).
- Building footprints.

### 3.4.2 Buildings and Roads

Buildings and roads were digitised using a multi-faceted approach. Many of these features were pre-classified to a reasonable degree of precision within the 2019 LAS dataset. These features were extracted and manipulated to create polygon datasets. A series of post-processing methods were then applied, including:

- Vertex *vs* Area ratios for buildings, to remove misclassified trees from the database.
- Polygon regularisation of building footprints, to generate clean boundaries and right angles.
- Polynomial Approximation with Exponential Kernel (PAEK) smoothing of road boundaries, to improve the precision of road edges for straight and curved segments (such as cul-de-sacs).
- Semi-automated removal of features with areas less than $10m^2$.
- Semi-automated removal using intersection analysis of misclassified buildings from parked cars, boats, trucks and trains.

Following completion of post-processing, buildings were layered into Council's previous database where the building was shown to be new or where the overall area would increase by at least $65m^2$. This value was determined by evaluating the minimum number of changes to achieve the majority cumulative area added to the database.

This ensured that the vast major of impervious area was captured within the building database without adding significant noise or error to Council's database. The outcomes of this approach can be summarised as follows:

- Any new buildings are captured.
- Recently constructed shelters and carports update the previous building footprint.
- Major changes at commercial centres (e.g. extensions) update the previous building footprint.
- Minor annexes and noise (such as jagged building edges) generally do not trigger a change to building footprint.

### 3.4.3 Waterbodies

Waterbodies were informed using the classified land extents within the LiDAR database. Consequently, updated waterbody extents are specific to the date of data capture, which will vary with water storage levels and tides.

This update produced several changes in the waterbodies layer, including:

- Significantly more rural waterbodies, due to automated digitisation.
- Updated active channel extents where there has been alluvial activity (generally estuarine areas).
- Reduction in clearwater openings in dense riparian zones. This may present an opportunity for further refinement and testing during subsequent modelling phases, whereby a minimum clearwater width may be adopted for larger systems.

Automated updates made to the waterbodies layer are critical to the viability of the vegetation understory density as it manages methodological constraints (discussed further in Section 3.4.4).

### 3.4.4 Vegetation Understory Density

In order to improve precision when predicting vegetation density, the project team adopted a new approach. This involved using vegetation classed LAS points within the first 2m above the ground to inform the 'understory density'. This height of vegetation was agreed with Council as being the critical range for most instances of modelling overland (urban, creeks and riverine) flow.

The method creates a relationship between vegetation and ground points at a resolution controlled by the point density of the point could. For this sample, a 4m$^2$ resolution was deemed as the upper limit of detail and was agreed with Council to be appropriate for use in the TUFLOW hydraulic models. It was also agreed that higher resolutions may inadvertently affect model stability, whilst significantly lower resolution (e.g. 10m$^2$) would omit important detail.

Using an automated workflow, a ratio of 0 – 1 (where 0 is no vegetation, 0.5 is 50% vegetation points and 50% ground points and 1 is 100% vegetation points) was created on a 4m grid for each LAS tile across the LGA. These processed tiles were combined to create a vegetation understory density. This process ensures density estimates are statistically comparative rather than predicted.

Vegetation was further separated into three types using available polygon databases – mangroves, crops and other vegetation (e.g. non-coastal riparian, terrestrial, urban).

#### 3.4.4.1 Site Visit

At this point, Council undertook a site visit to benchmark the accuracy and limitations of the new approach. The findings were also used to categorise the 0 – 1 ratio into low, medium and high-density classes. The following outcomes were drawn from the site visit findings:

- Out of 41 review locations, 85% of instances represented an acceptable or good representation of the on-ground roughness, consistent with traditional roughness assignment.
- Locations where a poor representation was predicted were a result of sub-grid features (such as unsealed footpaths) which are smaller than the grid size, changes in vegetation since data capture or limitations associated with the LiDAR data quality.

Based on the site visit findings, it was agreed the method was highly suited to consistently estimating vegetation understory density to inform hydraulic roughness in modelling.

### 3.4.5 Classification Categories

The final 2019 Landuse Condition Layers were separated into 15 categories base on landuse and land cover. The categories and corresponding code numbers have been listed in Table 3 against current and indicative ranges for Manning's values. Manning's values should be established through site visits and detailed calibration and validation against recent flood events (where data makes this possible).

Base vegetation layers were compiled in raster format on a 4m fixed grid. This was due to the consistent cover and raster product produced as part of the machine learning process. More dynamic layers such as waterbodies and infrastructure were digitised in shapefile polygon format. This allows for ease of future updates to the layers as well as the ability to overlay and stack layers on top of the base vegetation.

**Table 3 Landuse Classification Categories**

| Data Type | ID | Category | Current Manning's Value | Indicative Manning's Ranges[1] |
|---|---|---|---|---|
| Raster | 1 | Open Space (grasses) | 0.25 – 0.025 | 0.25 – 0.025 |
| | 2 | Low Density Understory – Vegetation | - | 0.050 - 0.075 |
| | 3 | Med. Density Understory – Vegetation | 0.075 – 0.150 | 0.075 – 0.100 |
| | 4 | High Density Understory – Vegetation | 0.090 – 0.180 | 0.100 – 0.150 |
| | 5 | Open Space – Mangroves (Marsh) | 0.040 | 0.030 – 0.040 |
| | 6 | Low Density Understory – Mangroves | 0.040 – 0.150 | 0.040 – 0.080 |
| | 7 | Med. Density Understory – Mangroves | | 0.080 – 0.160 |
| | 8 | High Density Understory – Mangroves | | Up to 0.250 |
| | 9 | Open Space – Crops (Fallow) | 0.040 | 0.030 – 0.040 |
| | 10 | Low Density Understory – Crops | | Specific to crop type. |
| | 11 | Medium Density Understory – Crops | | |
| | 12 | High Density Understory – Crops | | |
| Vector | 13 | Roads | 0.015 | 0.020 |
| | 14 | Concrete | | 0.015 |
| | 15 | Waterbody | 0.030 | 0.030[2] |
| | 16 | Buildings | 1.000 | 0.018 – 1.000[3] |
| | 17 | Horticulture Buildings | - | |
| | 18 | Railways | - | 0.050 – 0.100 |
| | 19 | Facilities | - | 0.025 |

[1]*Subject of calibration. Adopted values and depth-varying ranges may vary.*
[2]*Waterbodies should be modelled using bathymetric data and initial water levels to account for displacement.*
[3]*Low Manning's 'n' at shallow depths to model runoff for rain-on-grid models.*

## 3.5 Outcomes

The resultant 2019 Landuse Condition Layers were delivered to MBRC as an ArcGIS Layer Package File (.lpk) that contained the base layers raster and shapefile polygons listed in Table 3. The coverage areas and percentages of each landuse condition across all major basins is available in Table 4. A sample of the final 2019 Landuse Condition Layers is presented in Figure 4.

To support Council's initiative for ongoing maintenance of the RFD, instructions for updating the base landuse layers have been included in Appendix A.

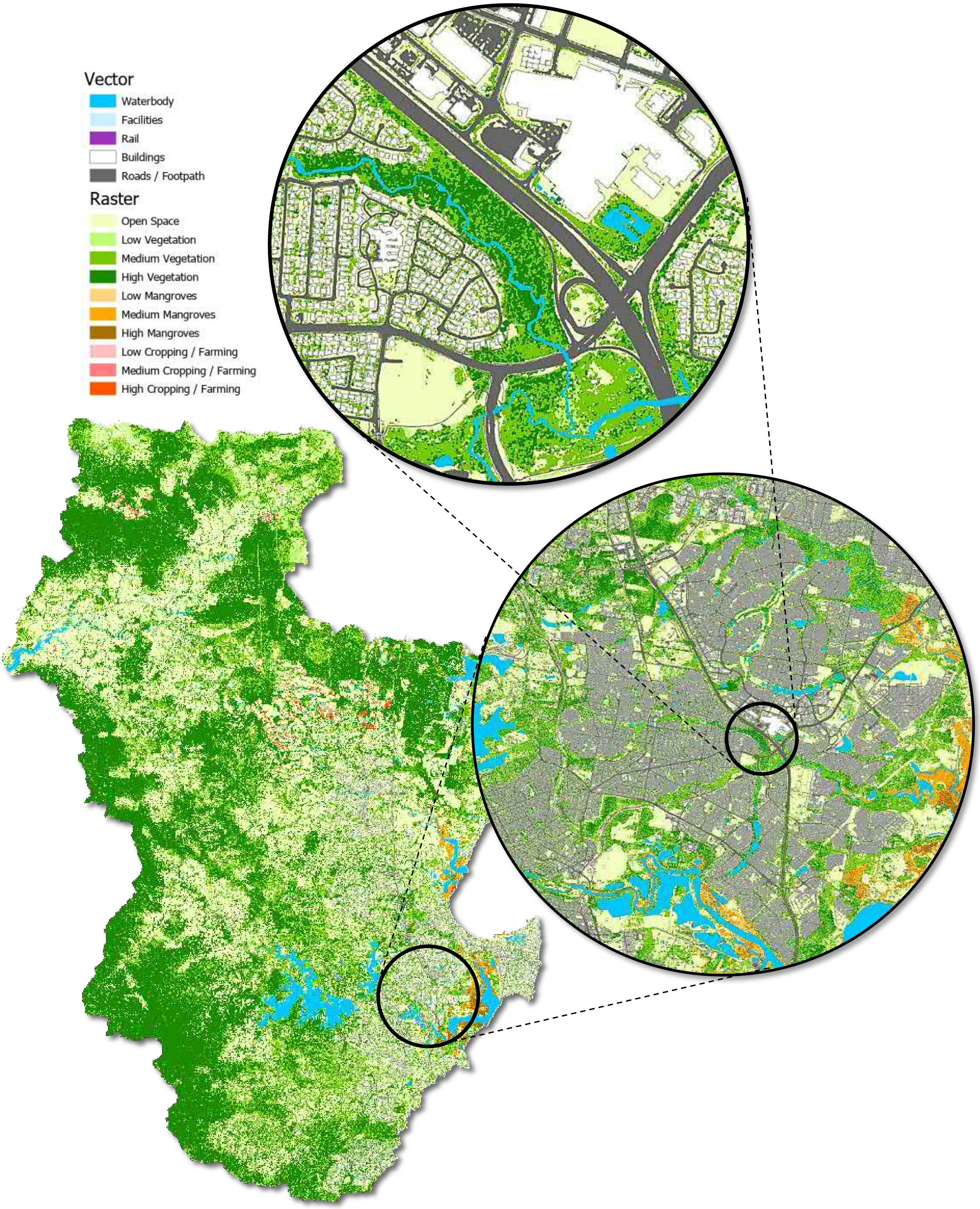



**Figure 4 Final 2019 Landuse Condition Layer**

**Table 4 Landuse Condition Layer Distributions**

| Minor Basin | Total Area (ha) | Area (ha) and Percentage of Cover | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Open Space | Vegetation | Mangroves | Crops / Farming | Roads | Concrete | Waterbody | Buildings | Facilities | Railway |
| BCR | 46,954 | 19,572 (41.7%) | 21,357 (45.5%) | 829 (1.8%) | 902 (1.9%) | 1,626 (3.5%) | 114 (0.2%) | 706 (1.5%) | 1,821 (3.9%) | 4 (<0.1%) | 24 (0.1%) |
| LPH | 38,782 | 12,001 (30.9%) | 19,331 (49.8%) | 1,454 (3.7%) | - | 1,947 (5.0%) | 305 (0.8%) | 1130 (2.9%) | 2,578 (6.6%) | 3 (<0.1%) | 33 (0.1%) |
| SRN | 61,106 | 23,251 (38%) | 36,272 (59.4%) | - | 651 (1.1%) | 415 (0.7%) | 2 (<0.1%) | 368 (0.6%) | 146 (0.2%) | <1 (<0.1%) | - |
| BRI | 5,188 | 1,388 (26.8%) | 3,121 (60.2%) | 19 (0.4%) | - | 249 (4.8%) | 12 (0.2%) | 116 (2.2%) | 283 (5.5%) | - | - |
| BCC | 4,023 | 1,015 (25.2%) | 2,310 (57.4%) | - | - | 279 (6.9%) | 13 (0.3%) | 6 (0.2%) | 394 (9.8%) | <1 (<0.1%) | 5 (0.1%) |
| BYR | 660 | 128 (19.4%) | 524 (79.4%) | - | - | 5 (0.7%) | - | 3 (0.5%) | <1 (0.1%) | - | - |
| MAR | 7,903 | 1,920 (24.3%) | 5,723 (72.4%) | - | 202 (2.6%) | 22 (0.3%) | - | 29 (0.4%) | 8 (0.1%) | - | - |
| PUM | 23,919 | 5,179 (21.7%) | 14,224 (59.5%) | 1,120 (4.7%) | 1,992 (8.3%) | 467 (2%) | 3 (<0.1%) | 669 (2.8%) | 259 (1.1%) | <1 (<0.1%) | 7 (<0.1%) |
| RED | 2,154 | 872 (40.5%) | 330 (15.3%) | 29 (1.4%) | - | 345 (16.0%) | 23 (1.1%) | 74 (3.5%) | 479 (22.2%) | 1 (0.1%) | - |
| SID | 5,259 | 2,212 (42.1%) | 2,657 (50.5%) | - | - | 103 (2.0%) | <1 (<0.1%) | 239 (4.5%) | 45 (0.9%) | - | 2 (<0.1%) |
| UPR | 34,807 | 9,198 (26.4%) | 23,474 (67.4%) | - | - | 275 (0.8%) | <1 (<0.1%) | 1,756 (5.0%) | 104 (0.3%) | <1 (<0.1%) | - |
| ***Total*** | ***230,755*** | **76,736 (33.3%)** | **129,323 (56.0%)** | **3,451 (1.5%)** | **3,747 (1.6%)** | **5,733 (2.5%)** | **472 (0.2%)** | **5,096 (2.2%)** | **6,117 (2.7%)** | **8 (<0.1%)** | **71 (<0.1%)** |

# 4.0 2019 Pervious-Impervious Raster

## 4.1 Overview

Once landuse layers were updated as part of the 2019 Landuse Condition Layers task, a pervious-impervious raster was created. The GIS and ML assessments undertaken during the previous task were leveraged to automate an efficient assessment of impervious percentage across the study area.

## 4.2 Impervious Cover

Impervious Cover Proportion for the Moreton Bay LGA was developed through the application of the ArcGIS tool “zonal statistics” to a raster dataset compiled from the results of the 2019 Landuse Condition Layers.

Data used in the determination of Impervious Cover Proportion for the 2019 Pervious-Impervious Raster included:

- Buildings (100% impervious).
- Roads (100% impervious).
- Facilities, e.g. tennis courts (100% impervious).
- Concrete, including footpaths and carparks (100% impervious).
- Waterbodies (100% impervious).
- Railways (70% impervious).
- Open space / vegetation (0% impervious).

It is noted that the adoption of 100% impervious for many layers is only reasonable due to high precision of the layer datasets. Traditional practice tends towards lower precision (i.e. generally at an allotment level rather than the 1m grid adopted here) with which fraction impervious is estimated based on typical features within each zone.

The adoption of 70% for railways is based on Melbourne Water’s recommended range of 60-80% for railways and tramways (for more information, see here – https://www.melbournewater.com.au/sites/default/files/2018-03/Music-tool-guidelines.pdf).

## 4.3 Raster Generation

The individual datasets were converted to raster files with all impervious features given the adopted value (0.0, 0.7 or 1.0) to represent associated imperviousness. These raster files were then combined with the pervious area coverage to create a raster dataset that covered the entire LGA extent at a 1m resolution.

## 4.4 Outcomes

The resultant 2019 Pervious-Impervious raster was delivered to MBRC as a 1m gridded ESRI raster file. A sample of this layer is shown below in Figure 5.

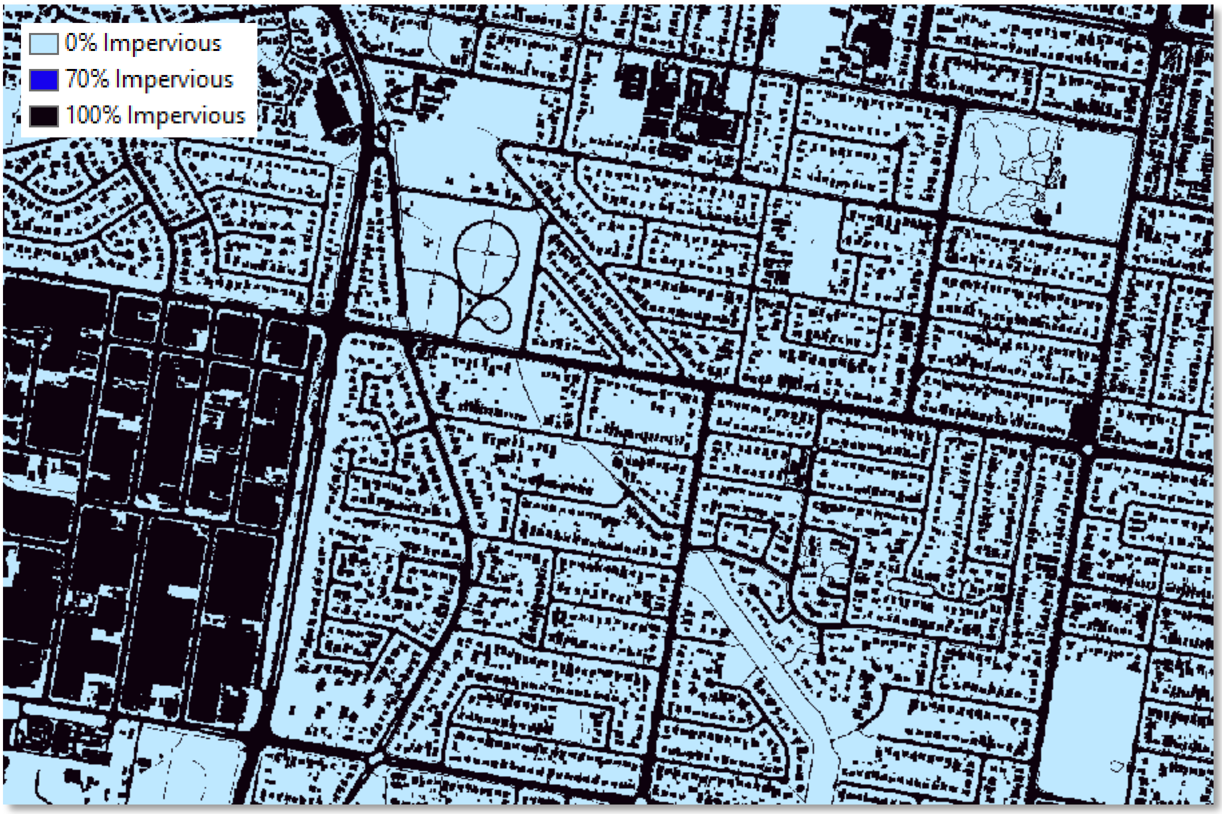



**Figure 5 2019 Pervious – Impervious Raster Sample (RED)**

This raster was then analysed at minor basin and minor catchments levels to understand the change in fraction impervious characteristics.

### 4.4.1 Minor Basins

The coverage areas and impervious percentages of each minor basin is presented in Table 5. These results have also been tabulated against the previously adopted fraction impervious (refer Section 2.3). From this comparison it was observed:

- The majority of increased imperviousness has occurred within the minor basins of BCR, LPH, BRI, BCC and RED.
- Minor basins which encompass large water storages (e.g. UPR, SRN), generally see a decrease in fraction impervious, indicating that the time at which this project was undertaken may be been drier than that used for the previous data.
- It is also noted that the dataset adopted for this project was captured within 2-hours of low tide, which would effectively reduce the extent of fraction impervious at the coastal boundary.
- The overall impervious area increased by more than 3,100ha across the full LGA.
- The greatest proportional increases were observed in LPH and RED. This is likely due to the following:
  - Some coastal minor catchments (outlets) within the lower reaches of LPH were incorrectly assigned a low FI over waterbodies.
  - Each have seen increases in urban density and commercial areas with large carparks.

**Table 5 2019 Pervious – Impervious Raster Statistics**

| Minor Basin | Area (ha) | Impervious Area (ha) | | | Impervious Fraction (%) | | |
|---|---|---|---|---|---|---|---|
| | | *Before* | *After* | *Change* | *Before* | *After* | *Change* |
| BCR | 46,954 | 3,508 | 4,278 | ▲770 | 7.5% | 9.1% | ▲1.6% |
| LPH | 38,782 | 3,795 | 5,988 | ▲2,193 | 9.8% | 15.4% | ▲5.6% |
| SRN | 61,106 | 970 | 932 | ▼38 | 1.6% | 1.5% | ▼0.1% |
| BRI | 5,188 | 525 | 660 | ▲135 | 10.4% | 12.7% | ▲2.3% |
| BCC | 4,023 | 593 | 696 | ▲103 | 14.7% | 17.3% | ▲2.6% |
| BYR | 660 | 7 | 8 | ▲1 | 1.1% | 1.2% | ▲0.1% |
| MAR | 7,903 | 69 | 60 | ▼9 | 0.9% | 0.8% | ▼0.1% |
| PUM | 23,919 | 1,312 | 1,404 | ▲92 | 5.5% | 5.9% | ▲0.4% |
| RED | 2,154 | 736 | 923 | ▲187 | 34.2% | 42.9% | ▲8.7% |
| SID | 5,259 | 459 | 389 | ▼70 | 8.7% | 7.4% | ▼1.3% |
| UPR | 34,807 | 2,379 | 2,136 | ▼243 | 6.8% | 6.1% | ▼0.7% |
| ***Total*** | ***230,755*** | ***14,353*** | ***17,474*** | ***▲3,121*** | ***6.2%*** | ***7.6%*** | ***▲1.4%*** |

### 4.4.2 Minor Catchments

Changes in fraction impervious were further analysis at the minor catchment level to generate an appreciation for the distribution of change and outliers which may significantly contribute to a change in modelling outcomes. Figure 6 presents the difference between previous and updated estimates of FI, scaled using minor catchment area (where + is an increase in FI). In this way, general trends can be observed and significant changes within large minor catchments can be identified as outliers for review. Observations included:

- Changes in FI by ±70% or more are observed where development has occurred within a small minor catchment, or a waterbody extent has been revised to impervious.
- Significant changes (e.g. >20%) in large minor catchments are generally at outlets which span waterbodies (e.g. LPH).
- Significant changes (e.g. >20%) in small-moderate sized minor catchments are generally where dense residential or commercial development has occurred.
- 67% of minor catchments were within ±1% FI, 77% within ±5% FI and 95% within ±20% FI.

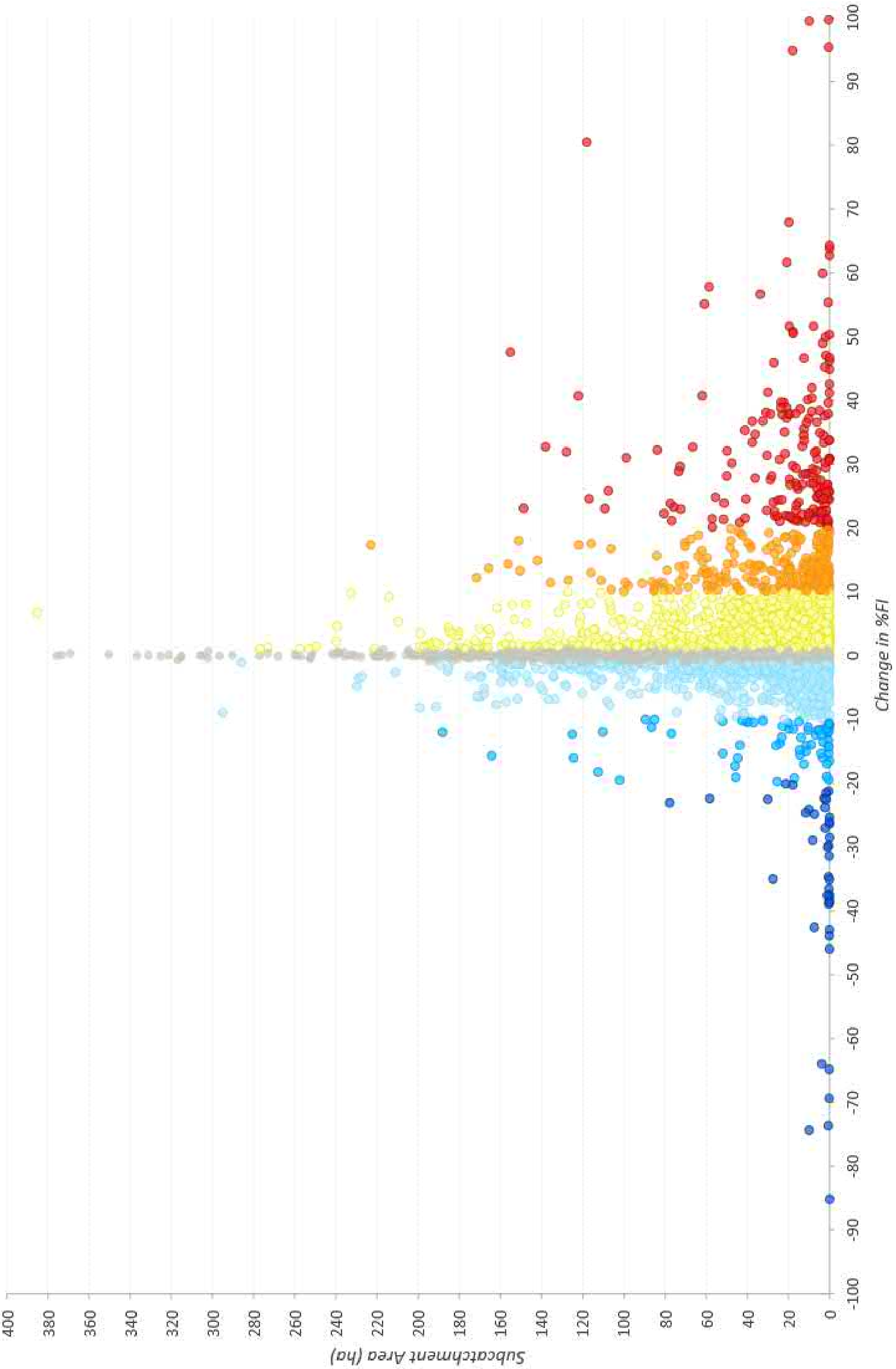



**Figure 6 Comparison of Change in %FI scaled by Minor Catchment Area**

# 5.0 2019 Conditions Hydrography Update

## 5.1 Overview

Hydrography layers (minor catchments, reaches and junctions) were reviewed and updated based on 2019 LiDAR and Imagery to capture changes with development and modified hydraulic controls. Several minor catchments were also refined in developed locations where the area notably exceeded 20ha.

## 5.2 Refinement Process

Prior to commencing detailed updates, the project team undertook an automated check of basin and creek extents to ensure boundaries were logical. Review of the predicted catchment extents confirmed the suitability of previous extents and generated assurance in the 2009 and 2014 LiDAR datasets used previously for catchment delineation.

Updates to hydrography layers were carried out in the following instances:

- New or previously ignored development, hydraulic structures or road crossings.
- Existing and proposed future stream gauges.
- Developed minor catchments which notably exceed 20ha, or areas specifically flagged for refinement by Council.
- An additional 151 structures were identified by Council for inclusion in the hydraulic models.

Based on these instances, the minor catchments layer was split or refined using 2019 LiDAR to inform the new catchment extent. Where this occurred over new development, Council's trunk stormwater infrastructure was used to inform logical boundaries. Following updates to the minor catchment boundaries, reaches were adjusted to match the latest channel invert using the 2019 LiDAR. Where reaches intersected other reaches at minor catchment boundaries, a junction was added. Figure 7 and Figure 8 present examples of the refinement exercise.

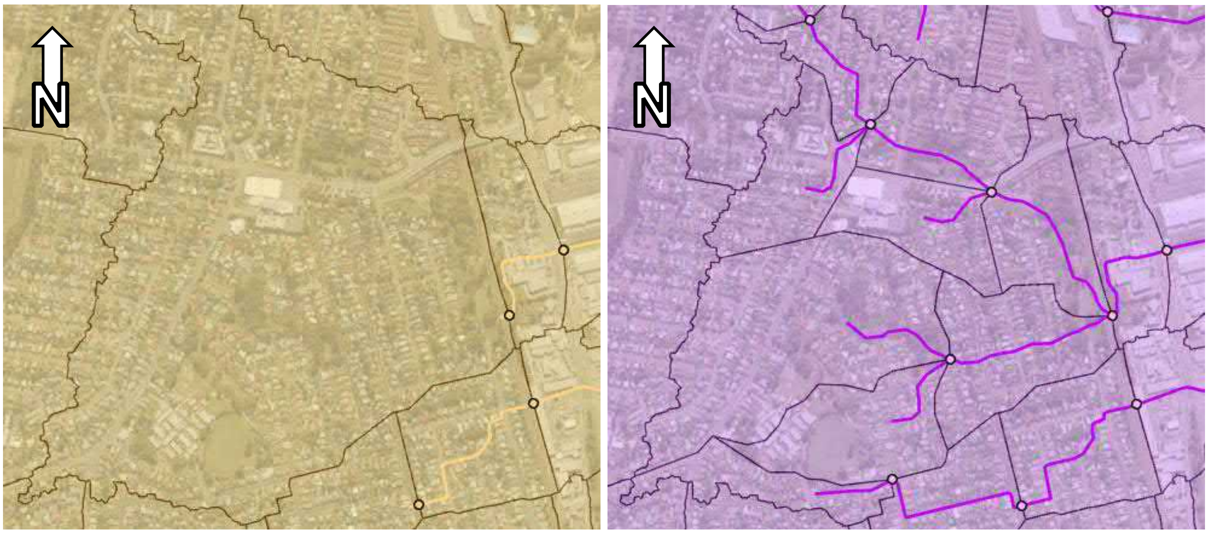



**Figure 7 Hydrography Refinement Sample 1 (Before – LHS | After – RHS)**

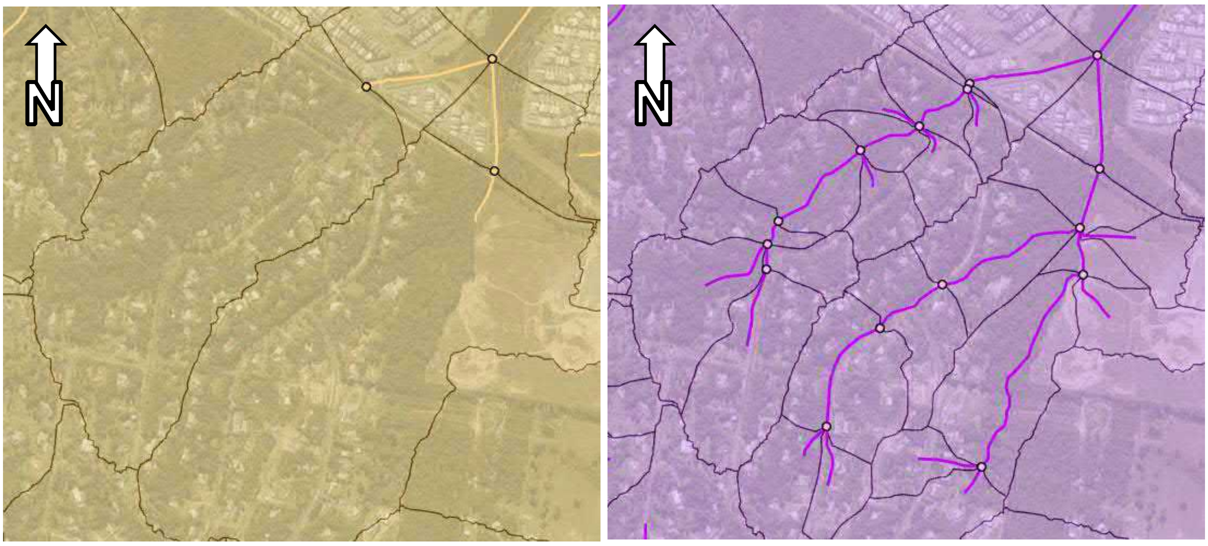



**Figure 8 Hydrography Refinement Sample 2 (Before – LHS | After – RHS)**

## 5.3 Naming Convention Updates

Together with spatial updates the following feature name attributes were updated:

- WW_ID
- DS_WW_ID
- STREAM_ID
- STREAM_NO

Naming parameters were adopted in accordance with Council's naming convention as follows:

- All tributaries located on the left of the primary reach (looking downstream) were allocated an odd number and those on the right were allocated an even number.
- Junctions are located at river/creek/tributary confluences, at structures (bridges and culverts) and at minor catchment boundaries. Streams are broken up into segments at the junctions. The chainage of the stream is used for naming the junctions.

A challenge was met where some minor basins saw more than 99 unique streams, which triggered a global update to the naming convention rather than formation of new minor basins. The change involved updating attribute character limits to allow stream numbers up to 999. This was agreed with Council as a favorable solution as it caters for future refinements and limits requirements to manually split catchments if the stream number exceeds 99. Examples of the naming structure updates are included in Table 6.

**Table 6 Global Naming Structure Updates**

<table>
<tr><th rowspan="2">Attribute</th><th colspan="2">Naming Template</th><th colspan="2">Example</th></tr>
<tr><th>Before</th><th>After</th><th>Before</th><th>After</th></tr>
<tr><td>WW_ID</td><td rowspan="2">XXX_XX_XXXXX<br>(12 chars)</td><td rowspan="2">XXX_XXX_XXXXX<br>(13 chars)</td><td>SPR_97_01138</td><td>SPR_097_01138</td></tr>
<tr><td>DS_WW_ID</td><td>SPR_97_00454</td><td>SPR_097_00454</td></tr>
<tr><td>STREAM_ID</td><td>XXX_XX<br>(6 chars)</td><td>XXX_XXX<br>(7 chars)</td><td>SPR_97</td><td>SPR_097</td></tr>
<tr><td>STREAM_NO</td><td>XX<br>(2 chars)</td><td>XXX<br>(3 chars)</td><td>97</td><td>097</td></tr>
</table>

## 5.4 Outcomes

Table 7 summarises the outcomes of the updates made to hydrography layers. Based on these statistics, significant changes in definition can be expected in BCR, LPH and BCC, where more than half of the minor catchments were refined into smaller catchments.

**Table 7 Hydrography Update Summary**

| Minor Basin | No. of Junctions | | | No. of Reaches & Minor Catchments | | |
|---|---|---|---|---|---|---|
| | *Before* | *After* | *Change* | *Before* | *After* | *Change* |
| BCR | 855 | 1,249 | ▲394 | 1,110 | 1,841 | ▲731 |
| LPH | 725 | 1,090 | ▲365 | 954 | 1,619 | ▲665 |
| SRN | 839 | 854 | ▲15 | 1,149 | 1,171 | ▲22 |
| BRI | 147 | 178 | ▲31 | 190 | 234 | ▲44 |
| BCC | 49 | 91 | ▲42 | 75 | 155 | ▲80 |
| BYR | 12 | 12 | - | 18 | 18 | - |
| MAR | 64 | 64 | - | 89 | 89 | - |
| PUM | 418 | 464 | ▲46 | 532 | 604 | ▲72 |
| RED | 167 | 181 | ▲14 | 214 | 244 | ▲30 |
| SID | 40 | 40 | - | 54 | 54 | - |
| UPR | 377 | 411 | ▲34 | 554 | 605 | ▲51 |
| ***Total*** | ***3,693*** | ***4,634*** | **▲*941*** | ***4,939*** | ***6,634*** | **▲*1,695*** |

# 6.0 2019 Conditions WBNM Modelling

## 6.1 Overview

2019 Conditions WBNM models were updated using the PIRs (Section 4.0) and revised hydrography (Section 5.0). Within this component of work, stream lag factors were also updated based on Council's latest stormwater infrastructure databases.

The following minor basins were also combined into single models:

- Burpengary Creek (BUR) & Caboolture River (CAB) → Burpengary Creek and Caboolture River (BCR);
- Lower Pine River (LPR) & Hays Inlet (HAY) → Lower Pine River and Hays Inlet (LPH); and
- Stanley River (STA) & Neurum Creek (NEU) → Stanley River and Neurum Creek (SRN).

## 6.2 Fraction Impervious Updates

Using the updated PIR raster, the average percent-impervious was re-estimated using zonal statistics for each minor catchment and assigned to the shapefile attribute. Comparison of before and after fraction impervious is included in Section 4.0.

## 6.3 Stream Lag Factor Updates

A considerable update to estimated stream lag factors was made in an effort to better quantify the speed of the flood water moving through drainage systems in developed areas. Review of the previous stream lag factors indicated the majority of minor basins use a consistent factor of 1, with some minor basins (BCC, UPR, LPH) adopting 0.75 or 0.50 across waterbodies.

In order to create a consistent, transparent approach to the stream lag factor estimate, a database of stream channel types was compiled using the channels GIS database and trunk infrastructure (i.e. pipes with diameters ≥900mm) from the stormwater asset database. The combination of these inputs provided a strong understanding of the features which influence stream lag factor estimation for each minor catchment.

The stream lag factor was then adopted by comparing the total reach length against the length of reach types (e.g. natural, concrete) for each minor catchment. Based on this analysis, the majority feature was adopted to inform the stream lag factor in accordance with Table 8. A spatial comparison of updates is presented in Figure 9 and Figure 10.

**Table 8 Adopted Stream Lag Factors**

| Predominant Stream Type | Stream Lag Factor |
|---|---|
| Natural channel | 1.00 |
| Semi-natural channel | 0.75 |
| Gravel bed with riprap | 0.67 |
| Excavated earth | 0.50 |
| Concrete lined | 0.33 |

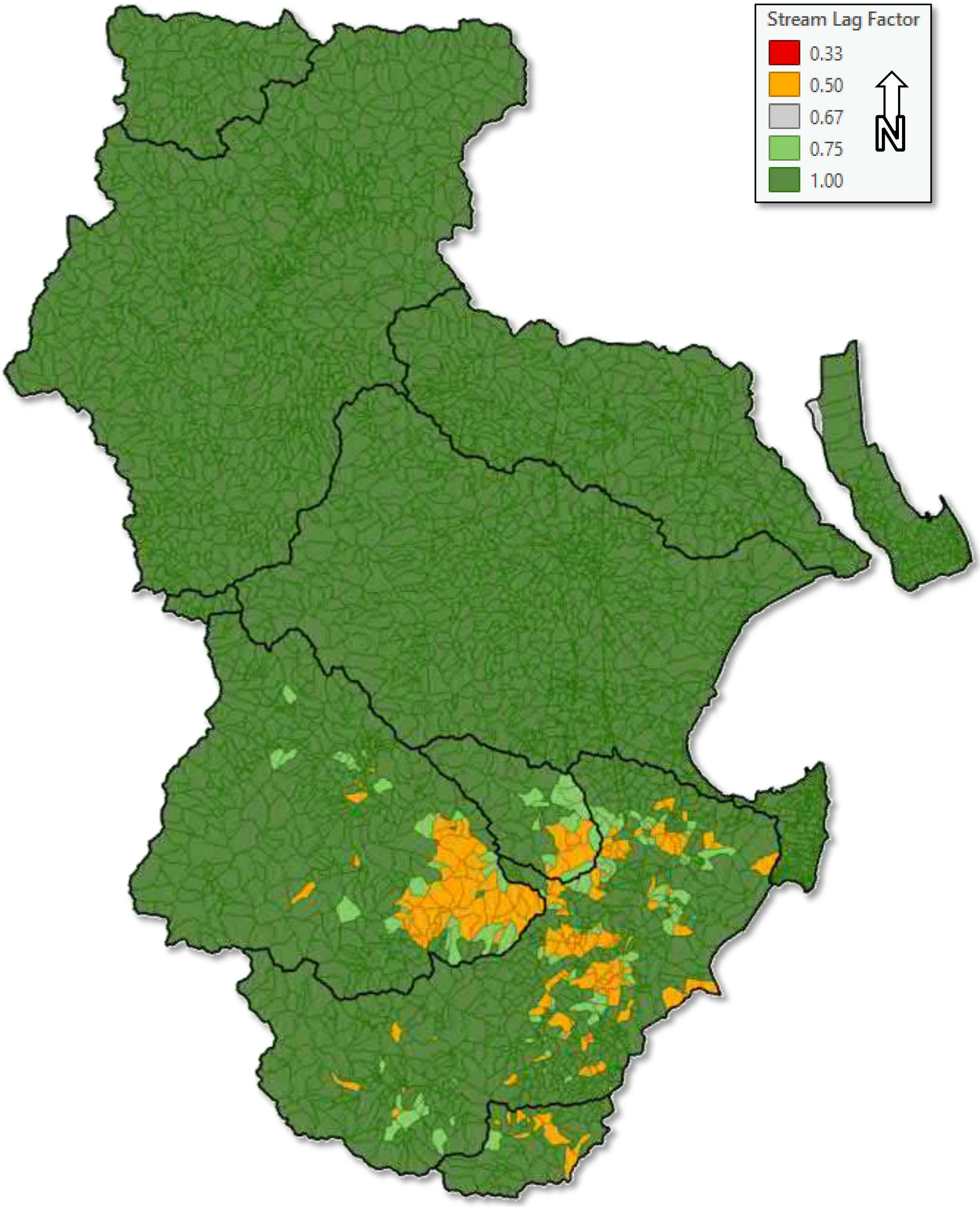



**Figure 9 Previous Stream Lag Factors**

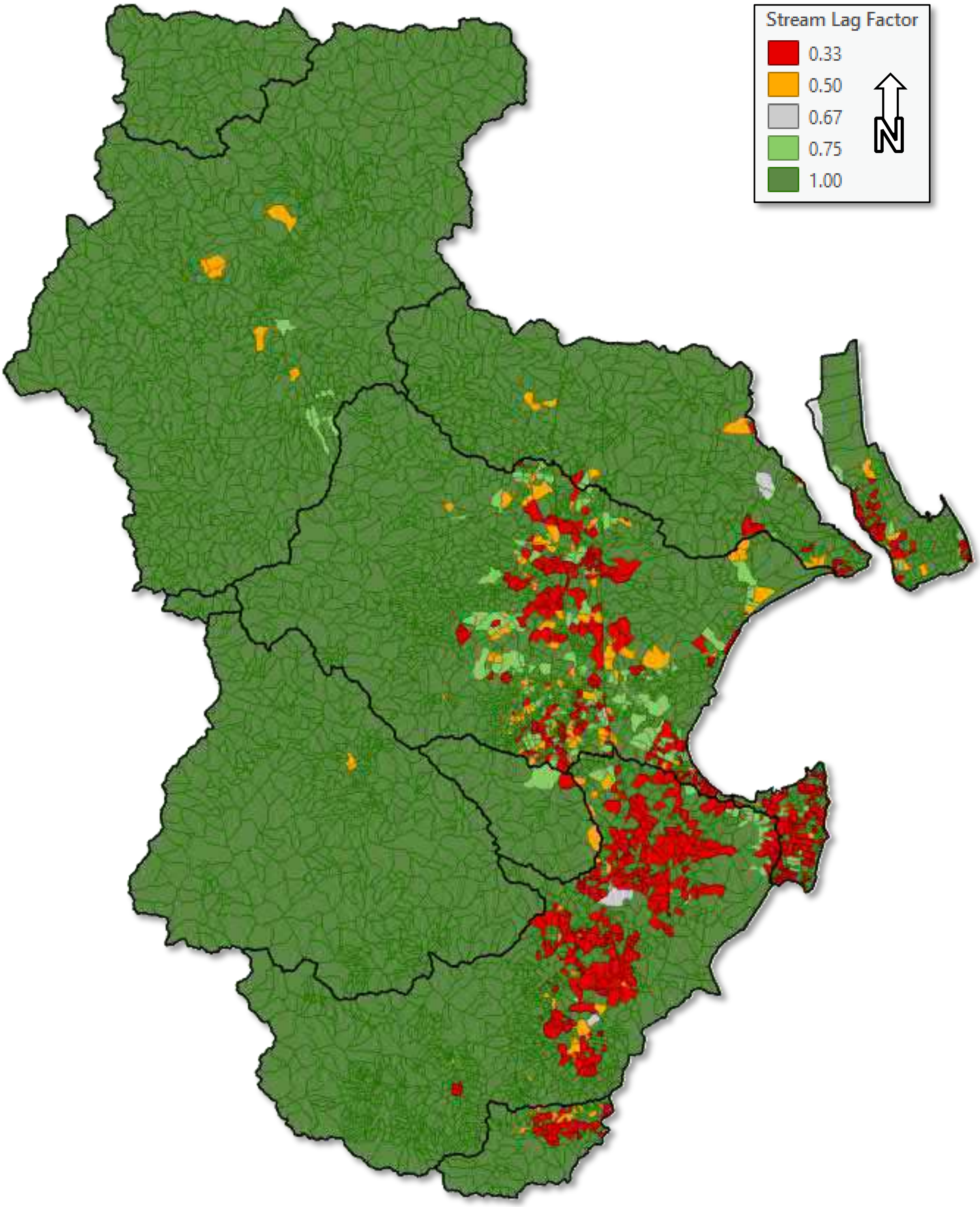



**Figure 10 Updated Stream Lag Factors**

## 6.4 Outcomes

Detailed hydrographs comparing previous and updated estimates are included in Appendix B. Table 9 summarises the change in peak flow and volume for each location identified by Council.

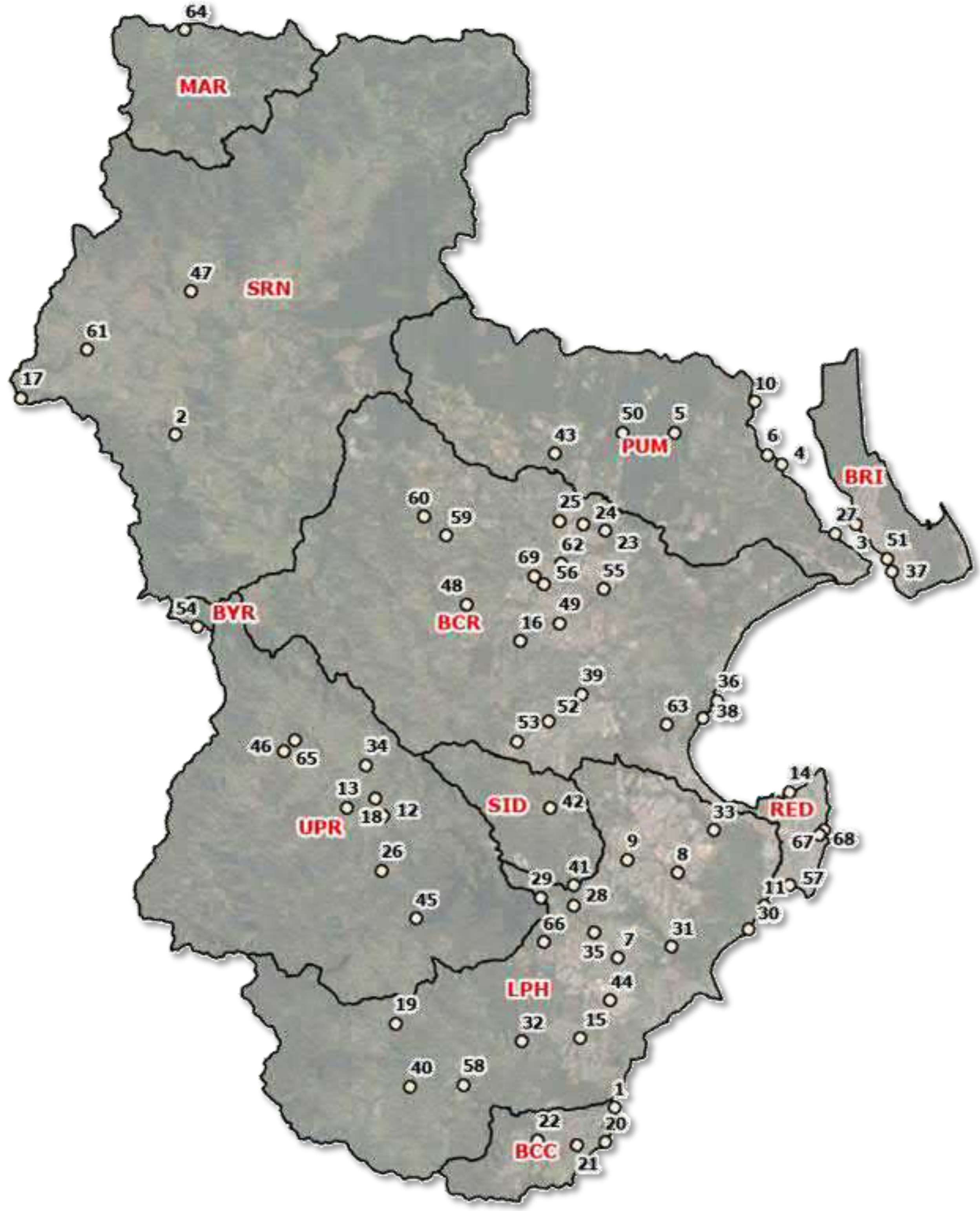



**Figure 11 Comparison Point Locations**

**Table 9 WBNM Performance Testing Summary**

| Minor Basin | Point ID | WW_ID (previous) | WW_ID (updated) | 5% AEP Peak Flow ($m^3/s$) | | | 5% AEP Volume ('000 $m^3$) | | | 1% AEP Peak Flow ($m^3/s$) | | | 1% AEP Volume ('000 $m^3$) | | | Cause of Significant Change (±20%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Before* | *After* | *Change* | *Before* | *After* | *Change* | *Before* | *After* | *Change* | *Before* | *After* | *Change* | |
| BCR | 1 | CBM_01_00000 | CBM_001_00000 | 1,252 | 1,228 | -2% | 27,289 | 33,124 | **21%** | 2,149 | 2,225 | 4% | 45,952 | 54,411 | 18% | Reduced lag factor, increased %FI in middle portion of catchment (Caboolture), particularly adjacent Bruce Highway. |
| | 2 | LAG_01_05523 | LAG_001_05523 | 208 | 198 | -5% | 3,636 | 3,584 | -1% | 351 | 356 | 1% | 5,624 | 5,743 | 2% | - |
| | 3 | KJC_01_26736 | KJC_001_26740 | 112 | 127 | 13% | 1,141 | 1,096 | -4% | 173 | 203 | 17% | 1,745 | 1,748 | 0% | - |
| | 4 | SSC_01_03651 | SSC_001_03651 | 142 | 141 | 0% | 1,898 | 1,840 | -3% | 228 | 238 | 4% | 2,907 | 2,936 | 1% | - |
| | 5 | CAB_01_13898 | CAB_001_13898 | 837 | 792 | -5% | 16,911 | 17,244 | 2% | 1,426 | 1,440 | 1% | 26,686 | 28,018 | 5% | - |
| | 6 | WAR_01_00778 | WAR_001_00778 | 350 | 323 | -8% | 6,875 | 6,832 | -1% | 600 | 590 | -2% | 10,718 | 11,046 | 3% | - |
| | 7 | SSC_01_07489 | SSC_001_07489 | 102 | 97 | -5% | 1,220 | 1,169 | -4% | 161 | 161 | 0% | 1,875 | 1,880 | 0% | - |
| | 8 | CAB_01_22731 | CAB_001_22731 | 454 | 431 | -5% | 8,815 | 8,796 | 0% | 768 | 776 | 1% | 13,851 | 14,335 | 3% | - |
| | 9 | WAR_01_10632 | WAR_001_10632 | 270 | 253 | -6% | 4,247 | 4,143 | -2% | 453 | 451 | 0% | 6,578 | 6,693 | 2% | - |
| | 10 | WAR_01_13474 | WAR_001_13474 | 252 | 238 | -6% | 3,674 | 3,570 | -3% | 417 | 417 | 0% | 5,682 | 5,766 | 1% | - |
| | 11 | KJC_01_24247 | KJC_001_24247 | 124 | 147 | **19%** | 1,444 | 1,406 | -3% | 194 | 236 | **21%** | 2,209 | 2,235 | 1% | Reduced lag factor upstream and minor increases in %FI. |
| | 12 | BUR_01_00000 | BUR_001_00000 | 415 | 525 | **27%** | 5,067 | 8,024 | **58%** | 690 | 882 | **28%** | 8,437 | 12,710 | **51%** | Cumulative effects of minor catchment refinements, broad increases in %FI and reductions in lag factors. |
| | 13 | BUR_01_24242 | BUR_001_23679 | 102 | 98 | -3% | 1,330 | 1,780 | **34%** | 173 | 178 | 3% | 2,220 | 2,887 | **30%** | Minor changes to lag factors, consistent increases in %FI. |
| | 14 | BUR_01_20827 | BUR_001_20285 | 103 | 100 | -2% | 1,361 | 1,954 | **44%** | 175 | 183 | 5% | 2,310 | 3,161 | **37%** | Minor changes to lag factors, consistent increases in %FI. |
| | 15 | BUR_01_15886 | BUR_001_15768 | 235 | 287 | **22%** | 2,956 | 3,967 | **34%** | 373 | 465 | **25%** | 4,830 | 6,322 | **31%** | Significant upstream minor catchment refinement with corresponding reduction in lag factors across development, consistent increases in %FI. |
| | 16 | CAB_01_09054 | CAB_001_09054 | 929 | 872 | -6% | 20,082 | 20,834 | 4% | 1,591 | 1,588 | 0% | 31,887 | 33,755 | 6% | - |
| | 17 | KJC_01_22289 | KJC_001_22289 | 155 | 180 | 16% | 2,014 | 1,957 | -3% | 249 | 295 | 18% | 3,081 | 3,097 | 1% | - |
| | 18 | LBC_01_03141 | LBC_001_03141 | 101 | 122 | **20%** | 1,146 | 1,232 | 7% | 160 | 194 | **21%** | 1,788 | 1,941 | 9% | Significant reduction in upstream lag factors for development areas and moderate increases in %FI. |
| LPH | 19 | CON_01_02616 | CON_001_02616 | 52 | 52 | 0% | 552 | 539 | -2% | 82 | 84 | 2% | 855 | 853 | 0% | - |
| | 20 | SID_01_01506 | SID_001_01506 | 322 | 306 | -5% | 4,740 | 4,815 | 2% | 520 | 522 | 0% | 7,433 | 7,834 | 5% | - |
| | 21 | SPR_01_13330 | SPR_001_13330 | 908 | 911 | 0% | 16,441 | 17,348 | 6% | 1,520 | 1,627 | 7% | 25,908 | 28,379 | 10% | - |
| | 22 | SPR_01_19187 | SPR_001_19216 | 888 | 888 | 0% | 14,885 | 15,395 | 3% | 1,473 | 1,569 | 7% | 23,279 | 25,168 | 8% | - |
| | 23 | SPR_01_33327 | SPR_001_33376 | 328 | 328 | 0% | 4,503 | 4,447 | -1% | 521 | 554 | 6% | 6,915 | 7,235 | 5% | - |
| | 24 | FMC_01_08326 | FMC_001_08327 | 77 | 82 | 7% | 973 | 964 | -1% | 125 | 137 | 9% | 1,505 | 1,511 | 0% | - |
| | 25 | FWC_01_13248 | FWC_001_13248 | 23 | 23 | 3% | 148 | 153 | 4% | 33 | 35 | 6% | 220 | 233 | 6% | - |
| | 26 | HAY_01_00000 | HAY_001_00000 | 349 | 450 | **29%** | 4,802 | 8,181 | **70%** | 585 | 756 | **29%** | 8,068 | 12,502 | **55%** | Significant reduction in upstream lag factors for development areas and significant increases in %FI. Hydrograph cut short in 002c. |
| | 27 | OMC_01_04319 | OMC_001_04319 | 89 | 93 | 5% | 1,048 | 1,024 | -2% | 147 | 154 | 5% | 1,661 | 1,645 | -1% | - |
| | 28 | PIN_01_00000 | PIN_001_00000 | 1,061 | 989 | -7% | 24,851 | 28,677 | 15% | 1,829 | 1,826 | 0% | 40,551 | 46,731 | 15% | - |
| | 29 | SAM_01_01293 | SAM_001_01293 | 198 | 216 | 9% | 2,404 | 2,336 | -3% | 312 | 362 | 16% | 3,674 | 3,807 | 4% | - |
| | 30 | TOD_01_01215 | TOD_001_01215 | 89 | 108 | **22%** | 681 | 674 | -1% | 133 | 159 | **20%** | 1,025 | 1,029 | 0% | Significant reduction in upstream lag factors. |
| | 31 | NPR_01_13848 | NPR_001_13848 | 1,297 | 1,159 | -11% | 31,149 | 31,402 | 1% | 2,231 | 2,154 | -3% | 49,975 | 51,801 | 4% | - |
| | 32 | FWC_01_08874 | FWC_001_08665 | 137 | 188 | **38%** | 1,346 | 1,426 | 6% | 207 | 284 | **37%** | 2,026 | 2,147 | 6% | Significant reduction in upstream lag factors for development areas and moderate increases in %FI. |
| | 33 | SWC_01_04807 | SWC_001_04807 | 219 | 273 | **24%** | 2,378 | 3,329 | **40%** | 357 | 447 | **25%** | 3,872 | 5,101 | **32%** | Significant minor catchment refinement upstream of site, significant reduction in lag factors across developed areas and significant increases in %FI. |
| | 34 | PIN_01_06869 | PIN_001_06869 | 1,069 | 1,003 | -6% | 24,210 | 26,645 | 10% | 1,834 | 1,843 | 0% | 38,708 | 43,249 | 12% | - |

| Minor Basin | Point ID | WW_ID (previous) | WW_ID (updated) | 5% AEP Peak Flow ($m^3/s$) | | | 5% AEP Volume ('000 $m^3$) | | | 1% AEP Peak Flow ($m^3/s$) | | | 1% AEP Volume ('000 $m^3$) | | | Cause of Significant Change (±20%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Before* | *After* | *Change* | *Before* | *After* | *Change* | *Before* | *After* | *Change* | *Before* | *After* | *Change* | |
| | 35 | NPR_01_10615 | NPR_001_10639 | 49 | 44 | -11% | 551 | 538 | -2% | 77 | 72 | -7% | 848 | 858 | 1% | - |
| | 36 | CED_01_15814 | CED_001_15814 | 208 | 216 | 4% | 3,371 | 3,382 | 0% | 345 | 381 | 11% | 5,184 | 5,506 | 6% | - |
| SRN | 37 | STL_01_06441 | STL_001_06441 | 1,967 | 1,867 | -5% | 28,363 | 44,367 | **56%** | 3,323 | 3,342 | 1% | 49,911 | 72,925 | **46%** | Hydrograph cut short in 002c. |
| | 38 | STL_01_00000 | STL_001_00000 | 2,335 | 2,199 | -6% | 25,980 | 56,244 | **116%** | 4,003 | 4,003 | 0% | 50,999 | 93,814 | **84%** | Hydrograph cut short in 002c. |
| | 39 | DEL_01_03830 | DEL_001_03830 | 295 | 277 | -6% | 4,768 | 5,223 | 10% | 509 | 509 | 0% | 7,718 | 8,557 | 11% | - |
| | 40 | STO_01_03418 | STO_001_03418 | 281 | 264 | -6% | 3,886 | 4,083 | 5% | 471 | 471 | 0% | 6,203 | 6,684 | 8% | - |
| BRI | 41 | DUX_01_00000 | DUX_001_00000 | 80 | 102 | **28%** | 839 | 1,345 | **60%** | 111 | 167 | **51%** | 1,186 | 1,852 | **56%** | Significant reduction in upstream lag factors for development areas and moderate increases in %FI across majority of upstream catchment. |
| | 42 | BON_01_00000 | BON_001_00000 | 32 | 33 | 3% | 236 | 245 | 4% | 42 | 48 | 15% | 324 | 332 | 3% | - |
| | 43 | BON_09_00000 | BON_009_00000 | 17 | 19 | 13% | 166 | 175 | 5% | 24 | 30 | **23%** | 233 | 239 | 3% | Minor reduction in upstream lag factors for development areas and moderate increases in %FI across majority of upstream catchment. |
| BCC | 44 | CTC_01_00000 | CTC_001_00000 | 51 | 75 | **46%** | 549 | 594 | 8% | 80 | 116 | 44% | 849 | 844 | -1% | Significant upstream minor catchment refinement and significant reduction in lag factors across developed areas. |
| | 45 | KED_01_00000 | KED_001_00000 | 241 | 253 | 5% | 2,665 | 3,257 | **22%** | 407 | 438 | 8% | 4,387 | 4,703 | 7% | Broad increases in %FI across majority of upstream catchment. |
| | 46 | KED_01_06294 | KED_001_06340 | 54 | 59 | 9% | 570 | 603 | 6% | 88 | 98 | 12% | 909 | 874 | -4% | - |
| | 47 | KED_01_02498 | KED_001_02532 | 232 | 228 | -1% | 2,464 | 2,770 | 12% | 379 | 391 | 3% | 3,979 | 4,006 | 1% | - |
| BYR | 48 | BYR_01_00000 | BYR_001_00000 | 70 | 66 | -6% | 576 | 604 | 5% | 110 | 110 | 0% | 926 | 1,002 | 8% | - |
| MAR | 49 | MAR_01_00367 | MAR_001_00367 | 265 | 251 | -5% | 2,912 | 3,504 | **20%** | 428 | 428 | 0% | 4,727 | 5,667 | **20%** | Hydrograph cut short in 002c. |
| PUM | 50 | BEE_01_00231 | BEE_001_00231 | 172 | 166 | -3% | 2,655 | 3,139 | 18% | 293 | 298 | 2% | 4,314 | 5,061 | 17% | - |
| | 51 | NIN_01_00000 | NIN_001_00000 | 212 | 199 | -6% | 3,411 | 4,379 | **28%** | 365 | 363 | 0% | 5,623 | 7,025 | **25%** | Hydrograph cut short in 002c. |
| | 52 | SMC_01_06731 | SMC_001_06731 | 336 | 319 | -5% | 4,507 | 5,279 | 17% | 559 | 562 | 1% | 7,284 | 8,513 | 17% | - |
| | 53 | ELI_01_16541 | ELI_001_16541 | 583 | 555 | -5% | 8,275 | 11,324 | **37%** | 995 | 1,003 | 1% | 14,004 | 18,370 | **31%** | Hydrograph cut short in 002c. |
| | 54 | GMC_01_00000 | GMC_001_00000 | 203 | 193 | -5% | 2,971 | 3,603 | **21%** | 345 | 347 | 0% | 4,863 | 5,816 | **20%** | Hydrograph cut short in 002c. |
| | 55 | ELI_11_00000 | ELI_011_00000 | 70 | 66 | -6% | 815 | 828 | 2% | 112 | 111 | -1% | 1,262 | 1,323 | 5% | - |
| | 56 | ELI_01_00000 | ELI_001_00000 | 584 | 558 | -4% | 5,126 | 12,731 | **148%** | 998 | 1,010 | 1% | 10,295 | 21,079 | **105%** | Hydrograph cut short in 002c. |
| RED | 57 | RCE_01_00000 | RCE_001_00000 | 22 | 29 | **33%** | 202 | 204 | 1% | 32 | 42 | **29%** | 292 | 296 | 1% | Reduced lag factor, increased %FI. |
| | 58 | RCN_01_00000 | RCN_001_00000 | 81 | 119 | **46%** | 690 | 803 | 16% | 117 | 171 | **47%** | 999 | 1,182 | 18% | Reduced lag factor, increased %FI. |
| | 59 | RCS_01_00082 | RCS_001_00082 | 36 | 46 | **27%** | 313 | 311 | -1% | 53 | 69 | **31%** | 458 | 462 | 1% | Reduced lag factor, increased %FI. |
| | 60 | RCE_01_00428 | RCE_001_00428 | 20 | 26 | **31%** | 165 | 165 | 0% | 29 | 37 | **28%** | 240 | 242 | 1% | Reduced lag factor, increased %FI. |
| SID | 61 | SID_01_09859 | SID_001_09859 | 72 | 69 | -5% | 1,191 | 1,227 | 3% | 123 | 124 | 1% | 1,898 | 2,022 | 7% | - |
| UPR | 62 | KOB_01_09533 | KOB_001_09533 | 299 | 280 | -6% | 4,425 | 4,394 | -1% | 495 | 495 | 0% | 7,047 | 7,174 | 2% | - |
| | 63 | KOB_18_02038 | KOB_018_02038 | 241 | 231 | -4% | 2,689 | 2,615 | -3% | 379 | 384 | 1% | 4,190 | 4,217 | 1% | - |
| | 64 | LAC_01_01837 | LAC_001_01837 | 404 | 375 | -7% | 7,316 | 7,356 | 1% | 689 | 687 | 0% | 11,746 | 12,080 | 3% | - |
| | 65 | TER_01_02218 | TER_001_02218 | 179 | 169 | -5% | 2,026 | 1,974 | -3% | 282 | 282 | 0% | 3,174 | 3,194 | 1% | - |
| | 66 | TER_01_05833 | TER_001_05833 | 105 | 100 | -5% | 1,214 | 1,179 | -3% | 166 | 166 | 0% | 1,903 | 1,914 | 1% | - |
| | 67 | NPR_01_32277 | NPR_001_32277 | 774 | 716 | -8% | 14,298 | 14,651 | 2% | 1,315 | 1,301 | -1% | 23,250 | 24,178 | 4% | - |
| | 68 | NPR_01_45197 | NPR_001_45197 | 277 | 261 | -6% | 3,642 | 3,594 | -1% | 458 | 452 | -1% | 5,870 | 5,894 | 0% | - |
| | 69 | NPR_01_35799 | NPR_001_35799 | 732 | 679 | -7% | 12,935 | 13,180 | 2% | 1,240 | 1,230 | -1% | 20,990 | 21,728 | 4% | - |

# 7.0 Conclusion & Recommendations

## 7.1 Conclusion

This project leveraged off high-resolution LAS and aerial imagery to construct detailed landuse condition layers as at 2019. Feature extraction, machine learning and point cloud data science techniques were used to created detailed layers for predominant types of landuse, including:

- Open spaces.
- Vegetation (crops, mangroves and other), which was further classified into density bands.
- Waterbodies.
- Sealed areas (bitumen and concrete).
- Building footprints.

These layers were generated at a 1m resolution in a consistent manner across the LGA and layered in Council's available databases to ensure quality information was maintained within the RFD update. Adoption of a semi-automated approach ensures human error and bias are kept to a minimum, with the remaining error a result of defined limitations with the process. To further increase confidence in the new layers and associated limitations, site visits were conducted to validate on-ground features. The result was a defendable, precise 2019 landuse conditions package across the LGA.

The 2019 landuse conditions layers were used to create updated percent-impervious rasters, which were in turn used to update impervious fractions within minor catchments. Hydrography layers (minor catchments, reaches and junctions) were also refined where development had occurred or more detail was needed to support subsequent modelling phases. Stream lag factors associated with each defined minor catchment were also re-estimated using Council's stormwater infrastructure databases.

Ultimately the inputs prepared above were applied in updated WBNM models and compared to previous estimates of peak flow and volume to understand the potential changes in predicted flood behaviour. Generally, increases in fraction impervious, minor catchment refinements and revised stream lag factors resulted in changes to peak flow and volume in urban areas (particularly dense urban areas) and minor changes in undeveloped areas.

## 7.2 Recommendations

The following recommendations are made for consideration moving forward:

- Future LAS / imagery capture projects should cover the whole LGA, as well as upper areas of STA and MAR basins.
- Any future LAS capture is semi-autonomously classified and should use reputable Point-CNN algorithms (if they exist at the time of processing) to improve feature classification.
- Aerial imagery is captured in a more consistent manner at midday on clear-sky occasions (if possible), as this will significantly improve the potential use cases of the dataset. A compromise may see adoption of lower resolution (e.g. 20cm, 30cm or 50cm).
- If possible, Near IR and Far IR bands should be included when capturing imagery and LAS, to improve classification of vegetation, differentiate between vegetation species and enable prediction of vegetation health. If captured at a similar resolution, this data could be used to expedite estimation of fraction impervious and some landuse features.
- Minor features such as footpaths should be digitised using a polyline centreline at a minimum, to bridge constraints of autonomous approaches such as large-scale AI.
- The effect of water storage levels on FI & WBNM hydrographs is sensitivity tested.
- Hydrography parameters (i.e. stream lag) are reviewed during subsequent calibration exercises.

# Appendix A

## Manual Update Methodology

# Appendix A Manual Update Methodology

## Updates to Polygons

1. Reshaping a polygon: https://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-existing-features/reshaping-polygons.htm
2. Splitting a polygon: https://desktop.arcgis.com/en/arcmap/10.3/manage-data/editing-existing-features/splitting-a-polygon.htm
3. Changing Landuse Classification: https://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/editing-a-value-in-a-table-cell.htm

## Updates to Rasters

4. Create new shapefile and add to ArcGIS.
5. Edit new shapefile and draw polygon(s) across extent requiring update.
6. Open attribute table and assign value to ID column based on Landuse Classification Categories set out in Table 3. Save edits and stop editing.
7. Convert shapefile to raster using "Feature to Raster" tool.
    - Input == new shapefile
    - Field == ID
    - Output Raster == *server location with name and file extension*
    - Output Cell Size == 1

    Check 'Source' properties of output raster and ensure 'Pixel Type' == unsigned integer and 'Pixel Depth' == 8.
8. Use 'Mosaic to New Raster' to merge raster updates into base raster. Drag in base raster (i.e. current landuse layer) in first, followed by output raster containing desired updates.
    - Output location == *server location*
    - Output name with extension == *name and file extension*
    - Spatial Reference for Raster == *GDA_1994_MGA_Zone_56*
    - Pixel Type == 8_BIT_UNSIGNED
    - Cell Size == 1
    - Number of bands == 1
    - Mosaic Operator == Last
    - Mosaic Colourmap Mode == First

## Updates Specific to TUFLOW

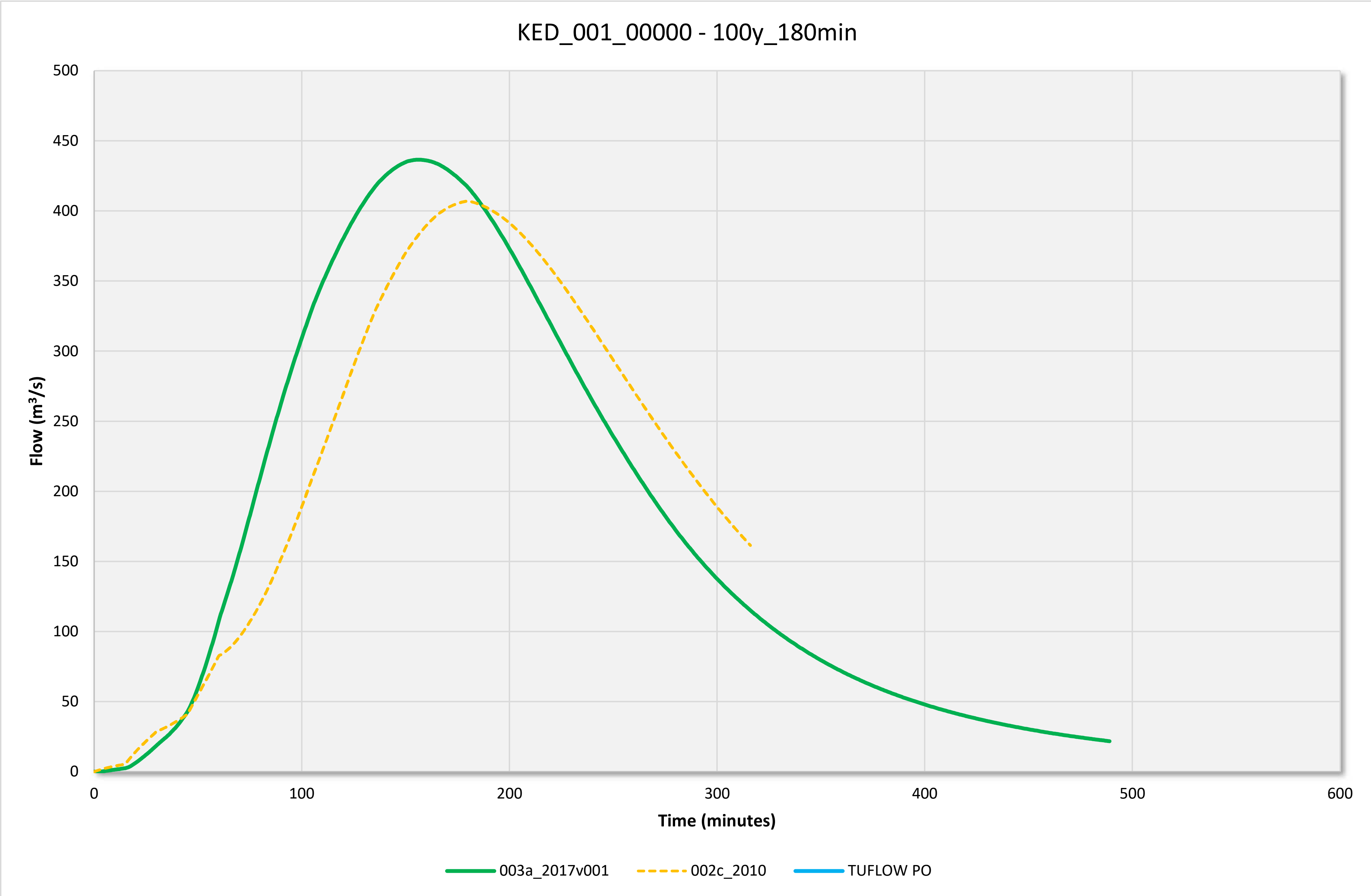
Updates for Manning's roughness files (2d_mat) in TUFLOW can be made by reading in a 2d_mat shapefile of updates after the base raster.

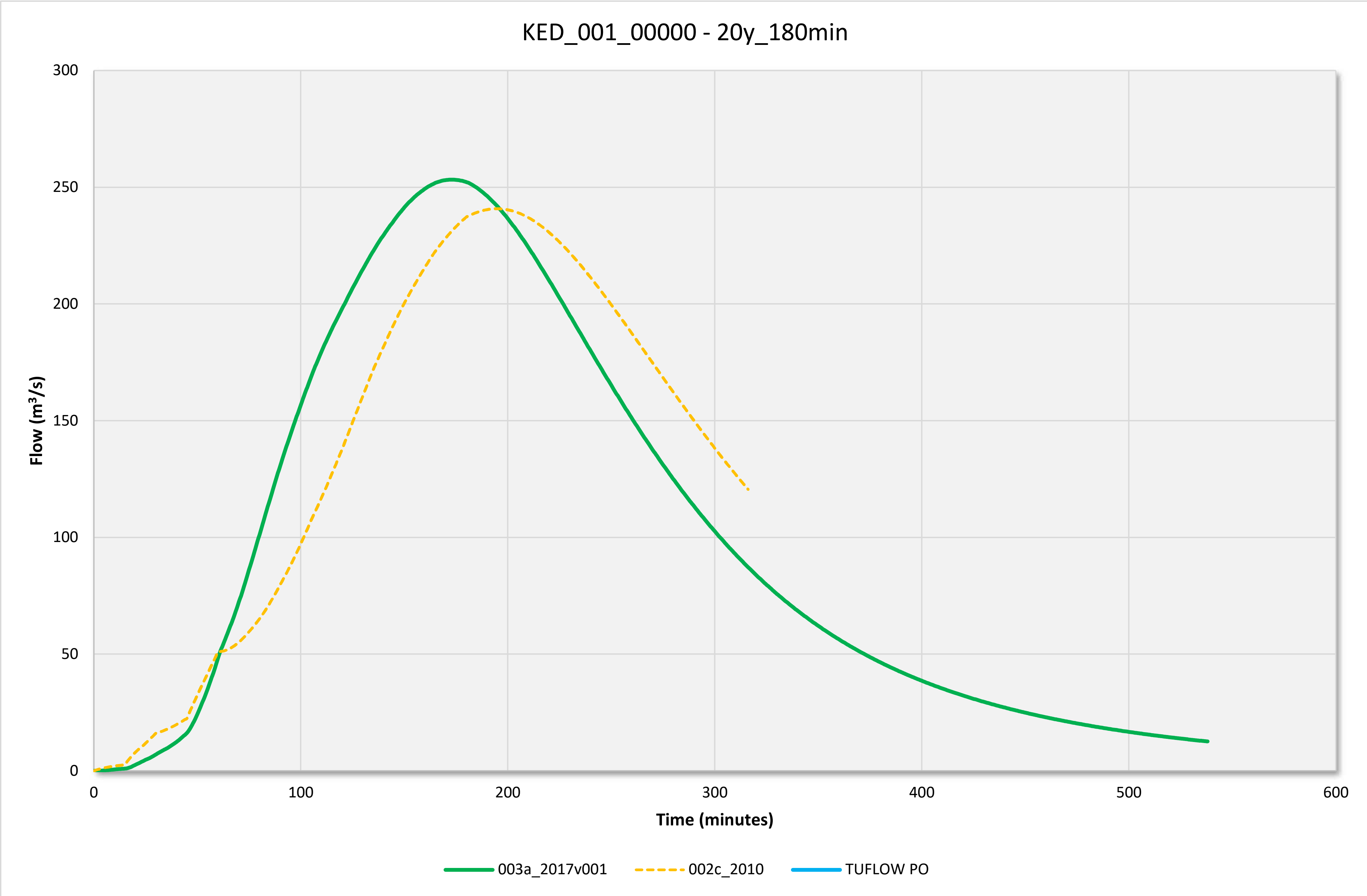
For the example below 'updates.shp' will supersede overlapping locations within 'base_raster.flt':

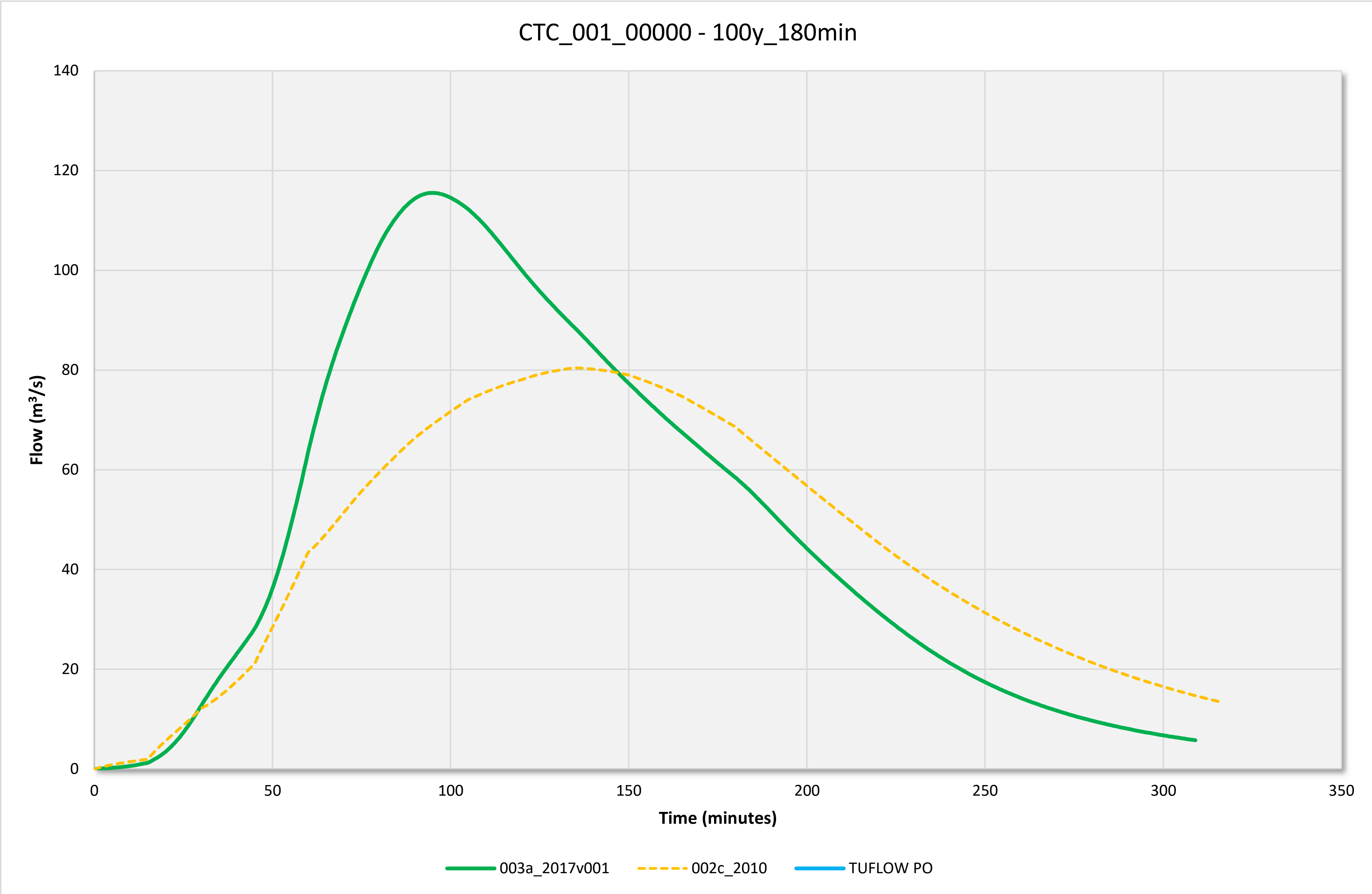
```
Read GRID MAT == base_raster.flt
Read GIS MAT == updates.shp
```

# Appendix B

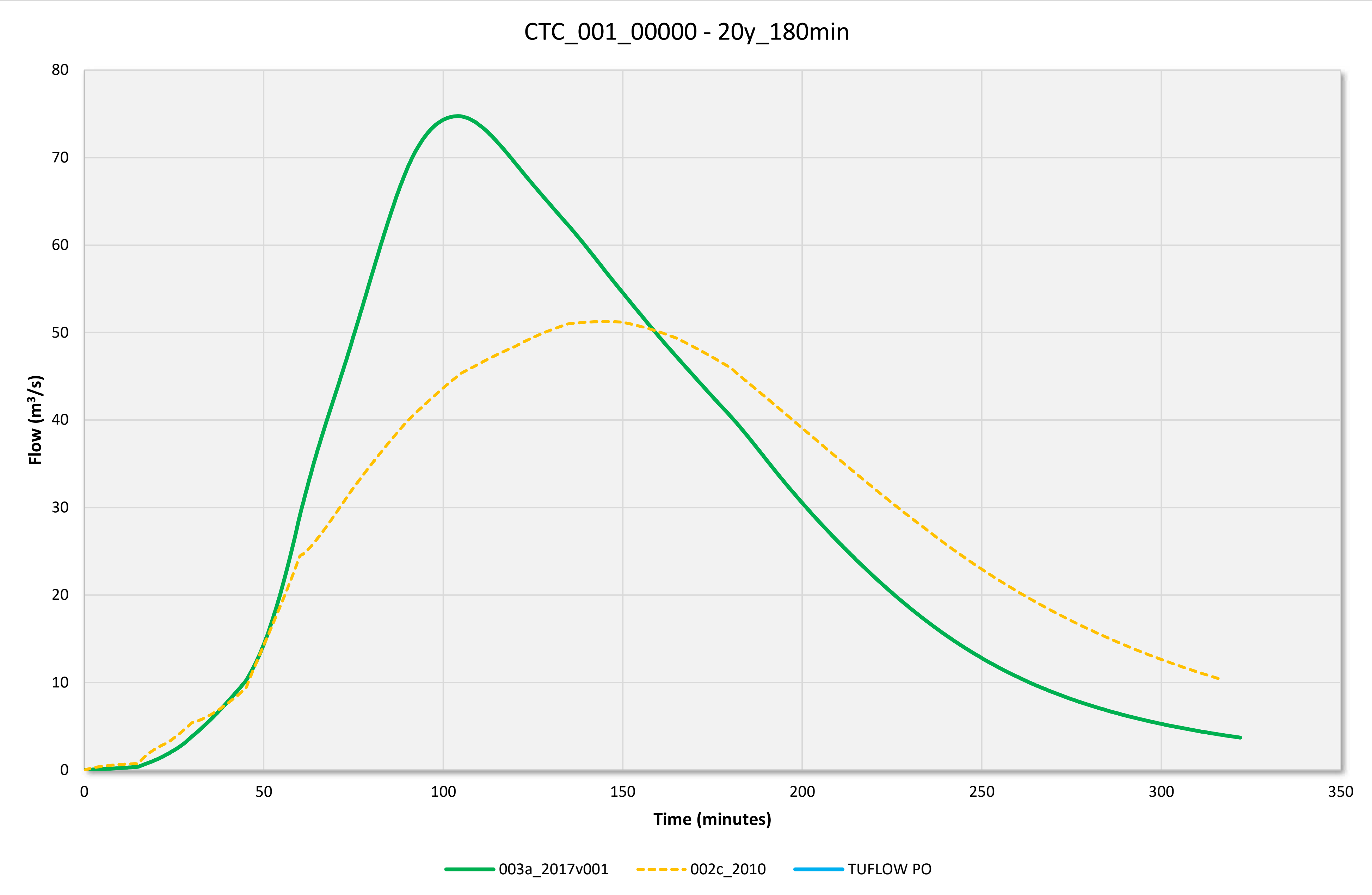
## WBNM Performance Testing Results


KED_001_00000 - 100y_180min
Flow (m³/s)
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

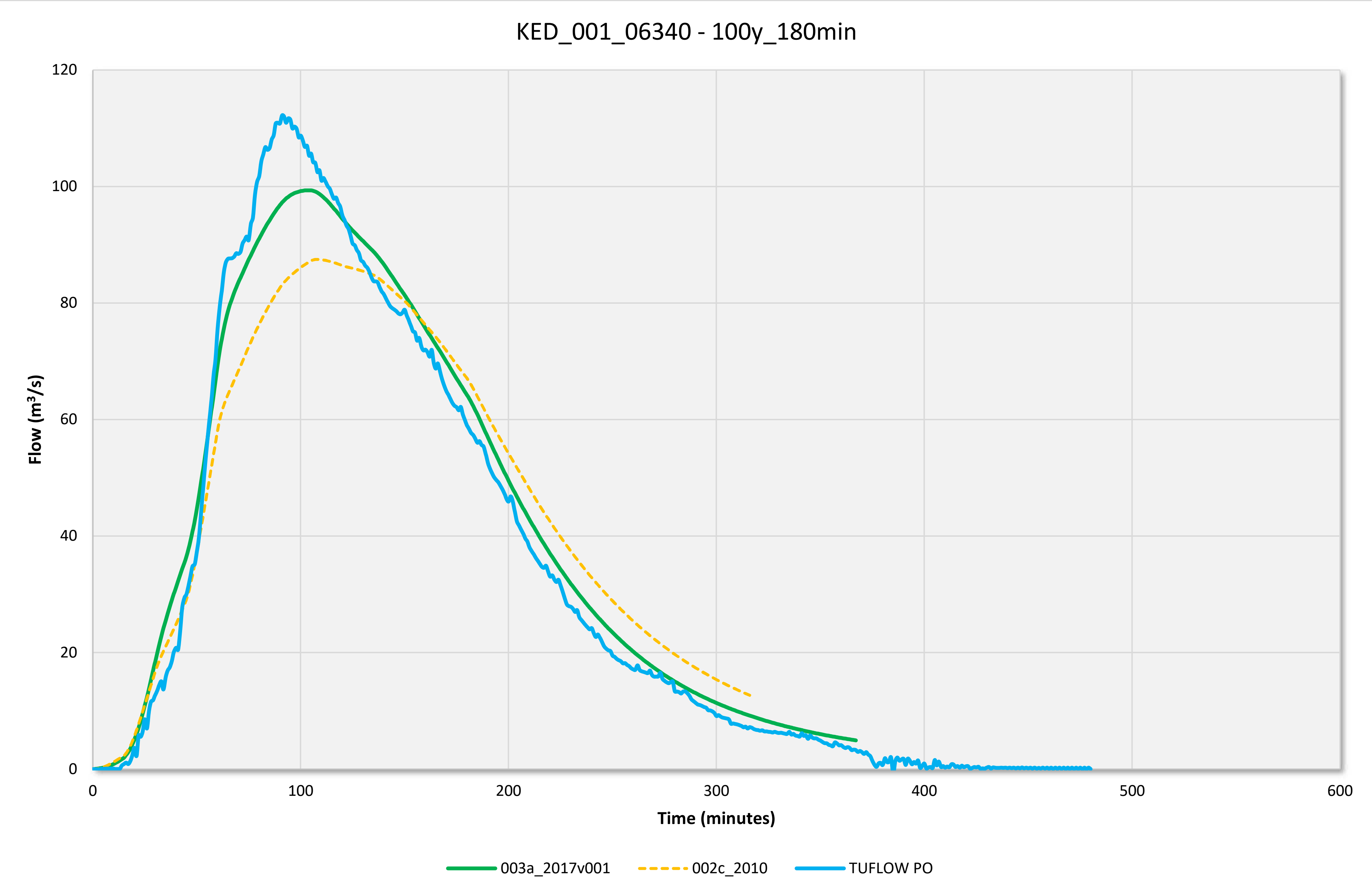

KED_001_00000 - 20y_180min
300
250
200
150
100
50
0
Flow (m³/s)
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



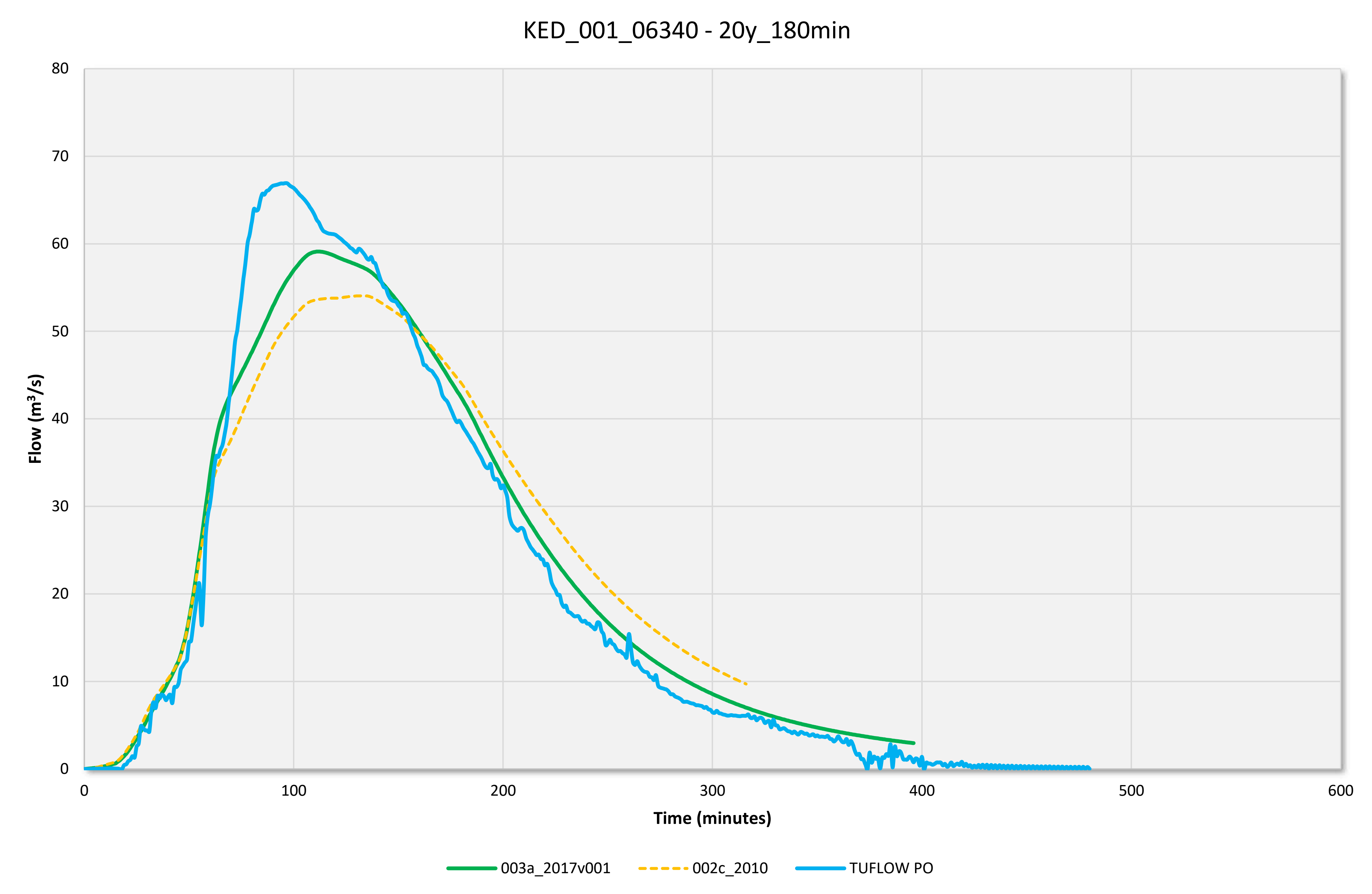
CTC_001_00000 - 100y_180min
140
120
100
80
60
40
20
0
Flow (m³/s)
0
50
100
150
200
250
300
350
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

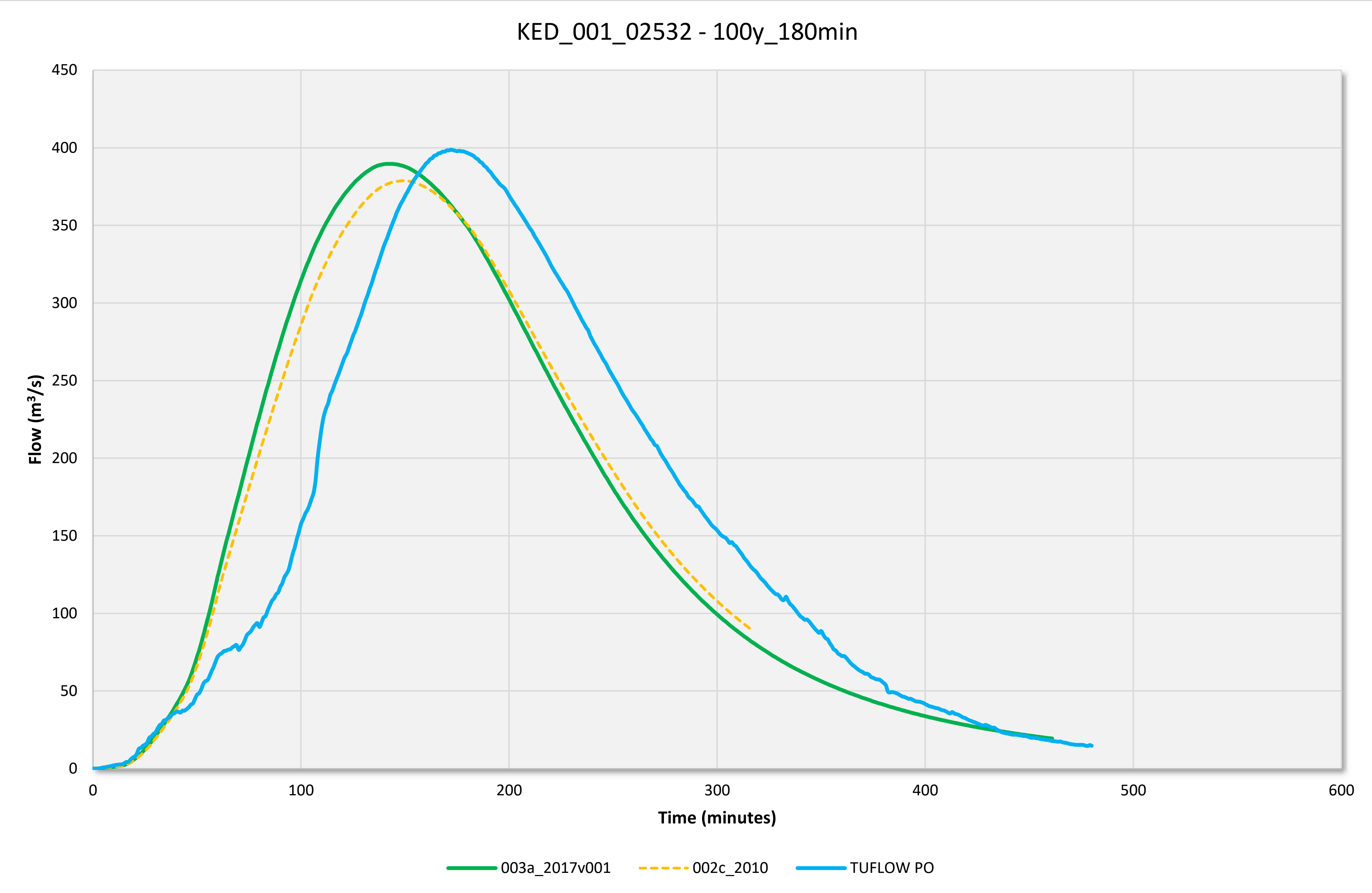


CTC_001_00000 - 20y_180min
Flow (m3/s)
Time (minutes)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
003a_2017v001
002c_2010
TUFLOW PO

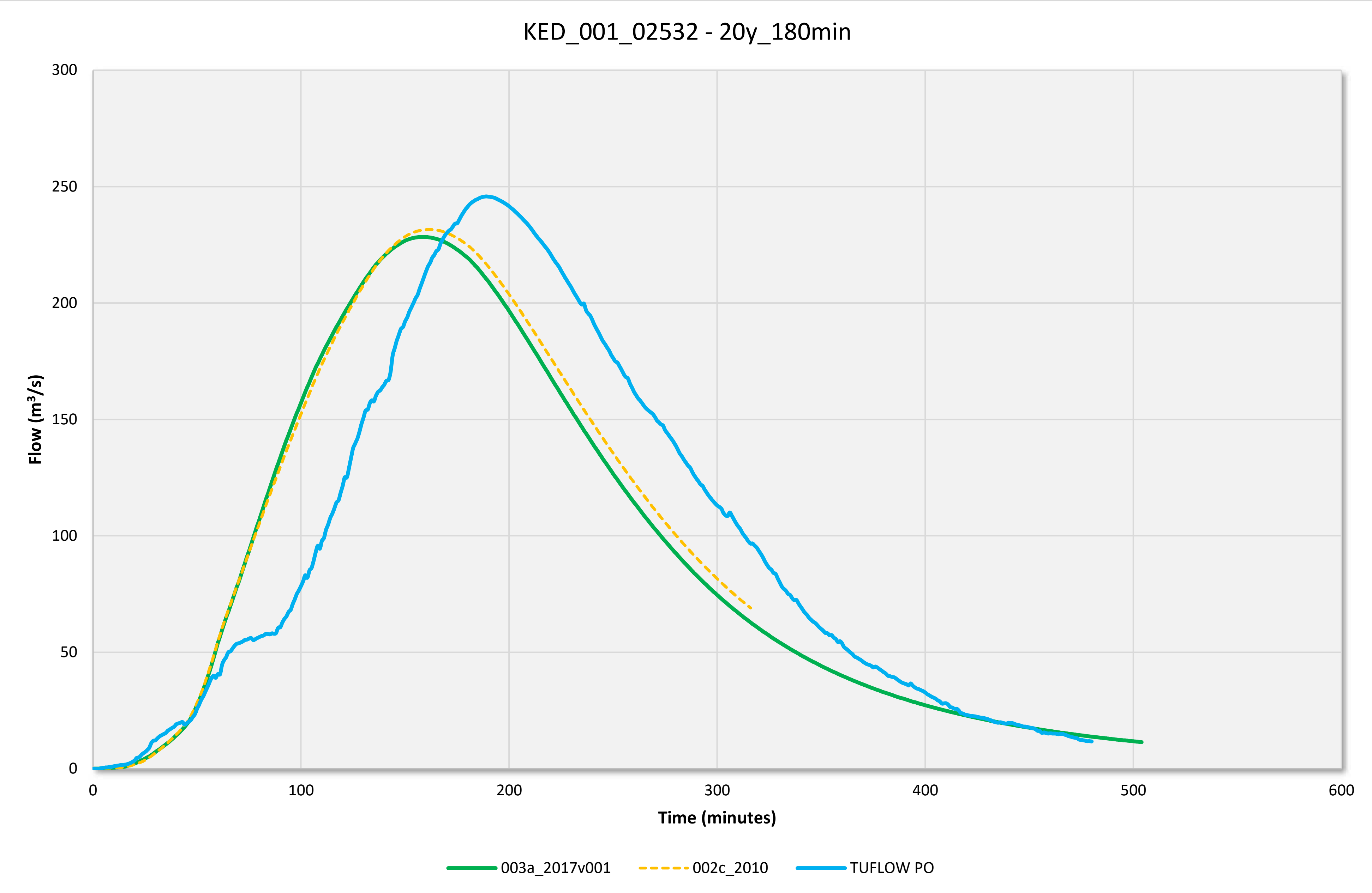


KED_001_06340 - 100y_180min
120
100
80
60
40
20
0
Flow (m³/s)
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

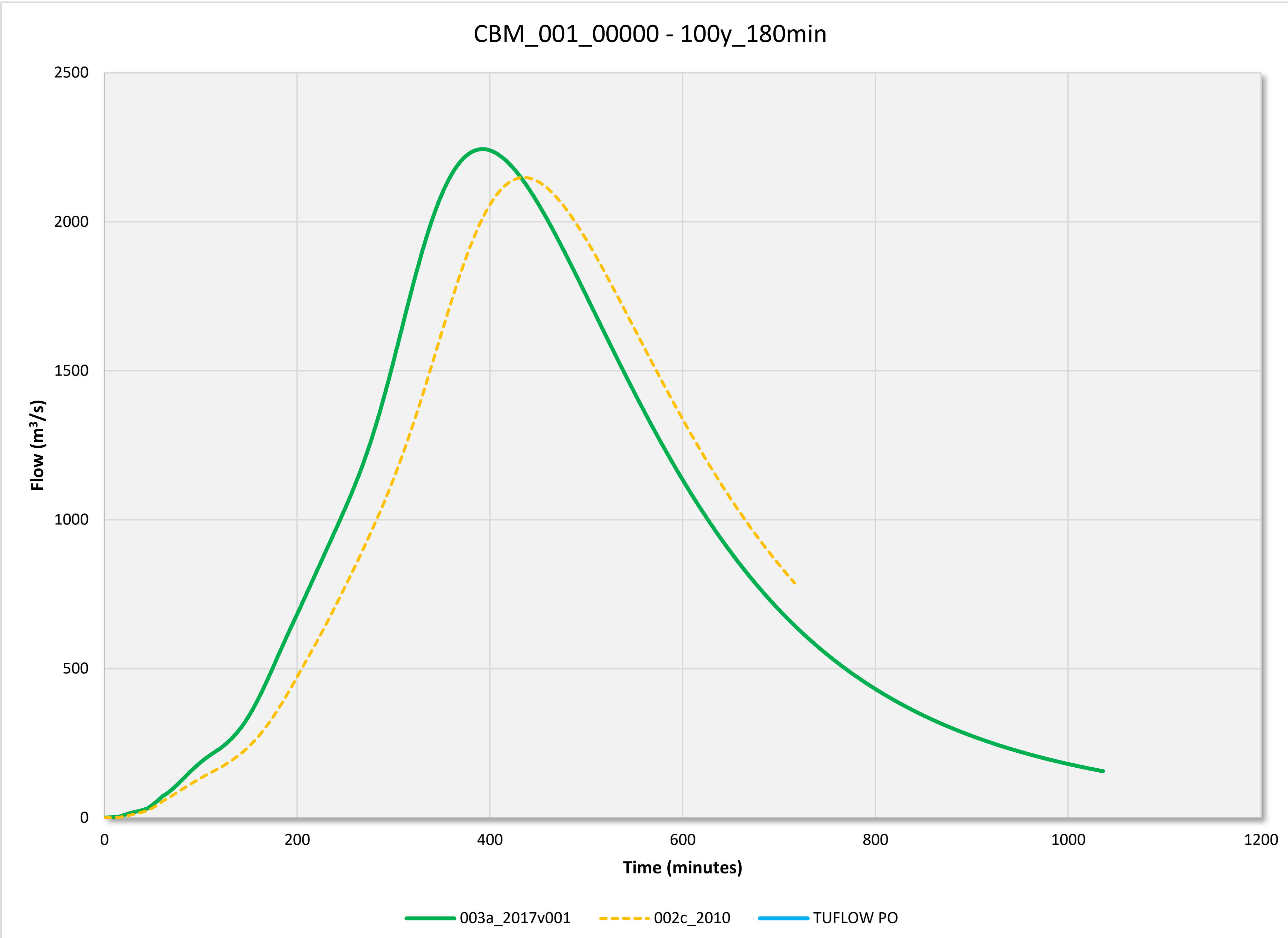

KED_001_06340 - 20y_180min
Flow (m³/s)
Time (minutes)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
003a_2017v001
002c_2010
TUFLOW PO

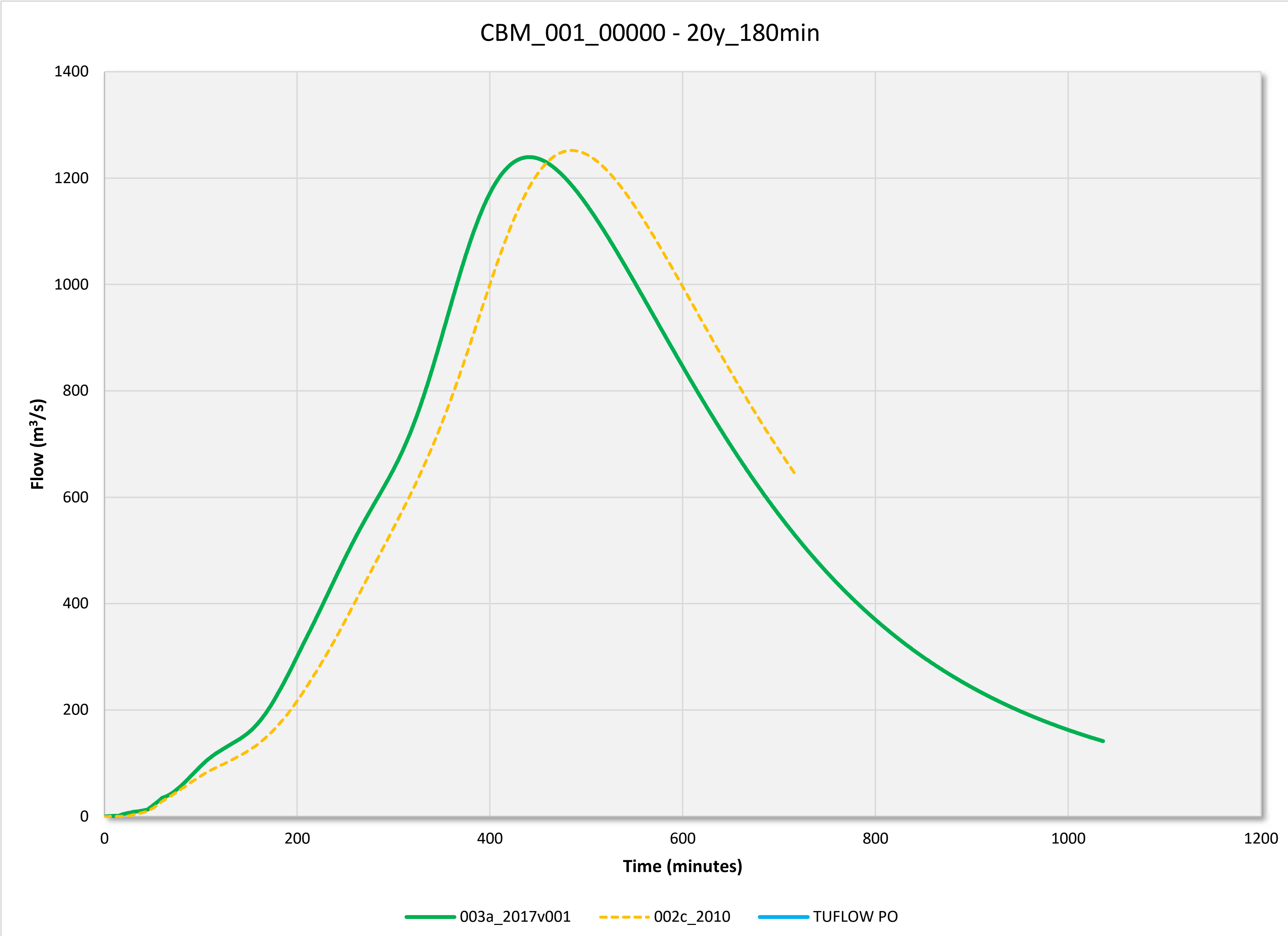


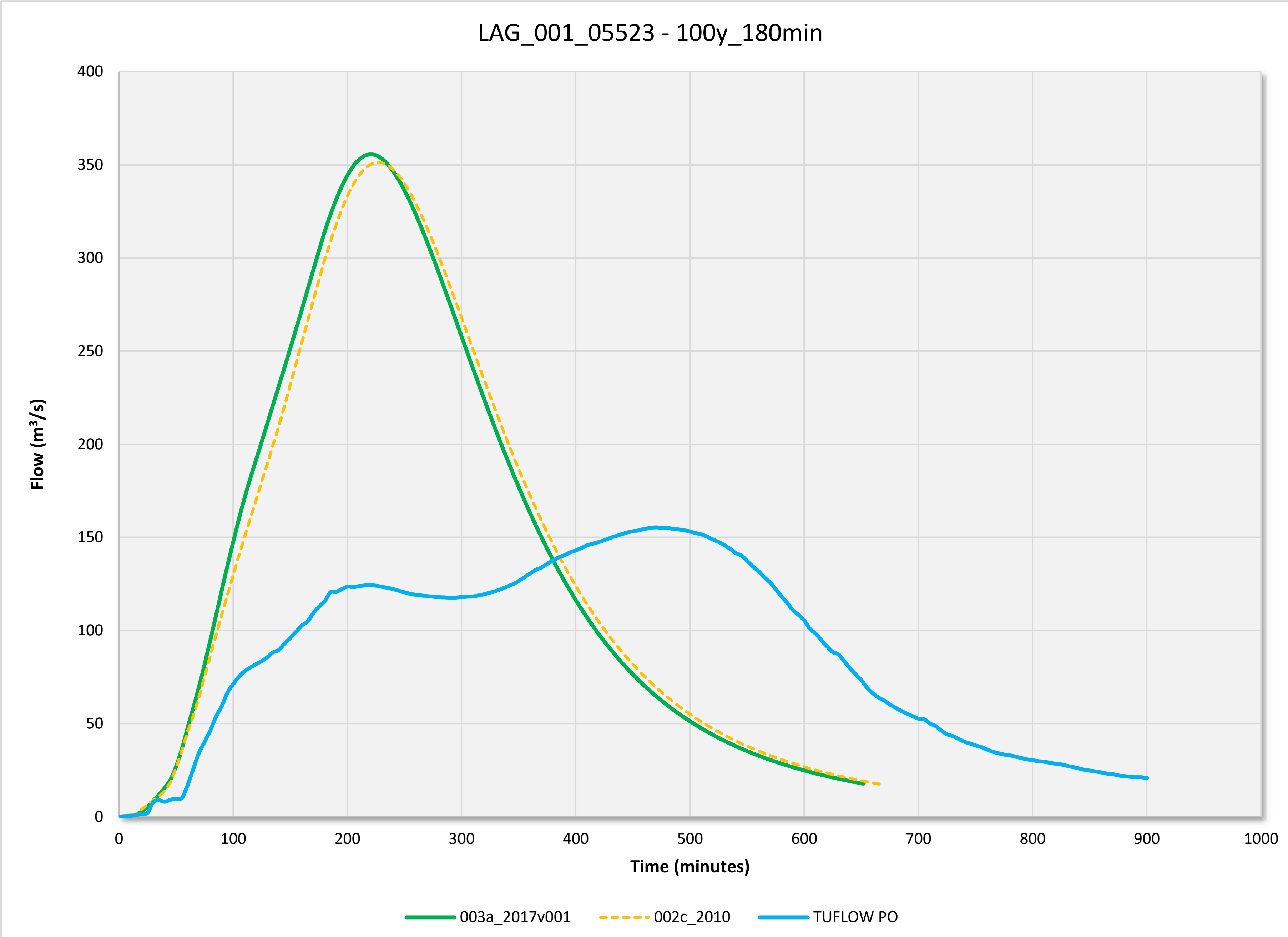
KED_001_02532 - 100y_180min
Flow (m³/s)
0
50
100
150
200
250
300
350
400
450
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

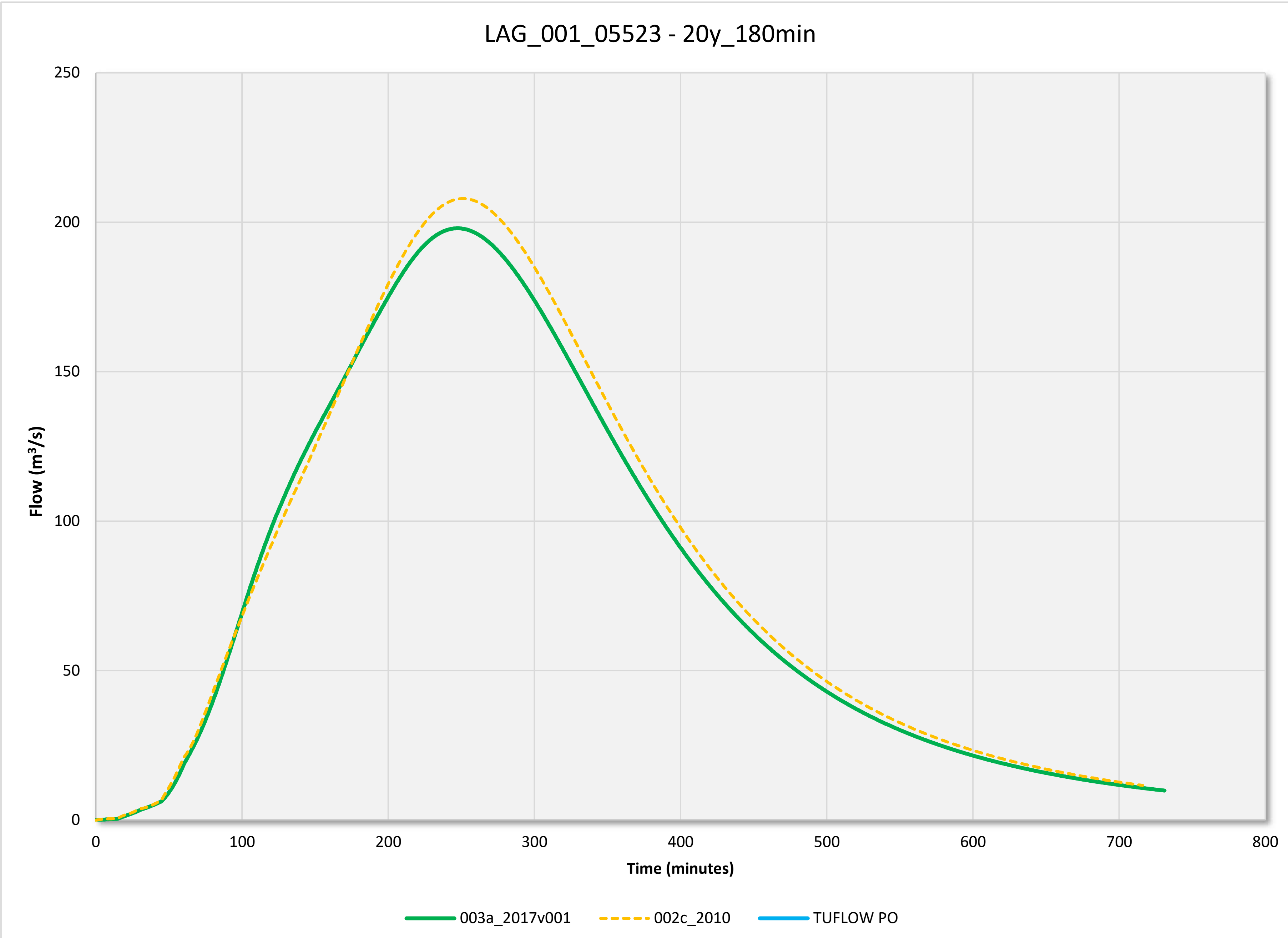


KED_001_02532 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


CBM_001_00000 - 100y_180min
Flow (m³/s)
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


CBM_001_00000 - 20y_180min
Flow (m³/s)
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


LAG_001_05523 - 100y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
600
700
800
900
1000
003a_2017v001
002c_2010
TUFLOW PO


LAG_001_05523 - 20y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
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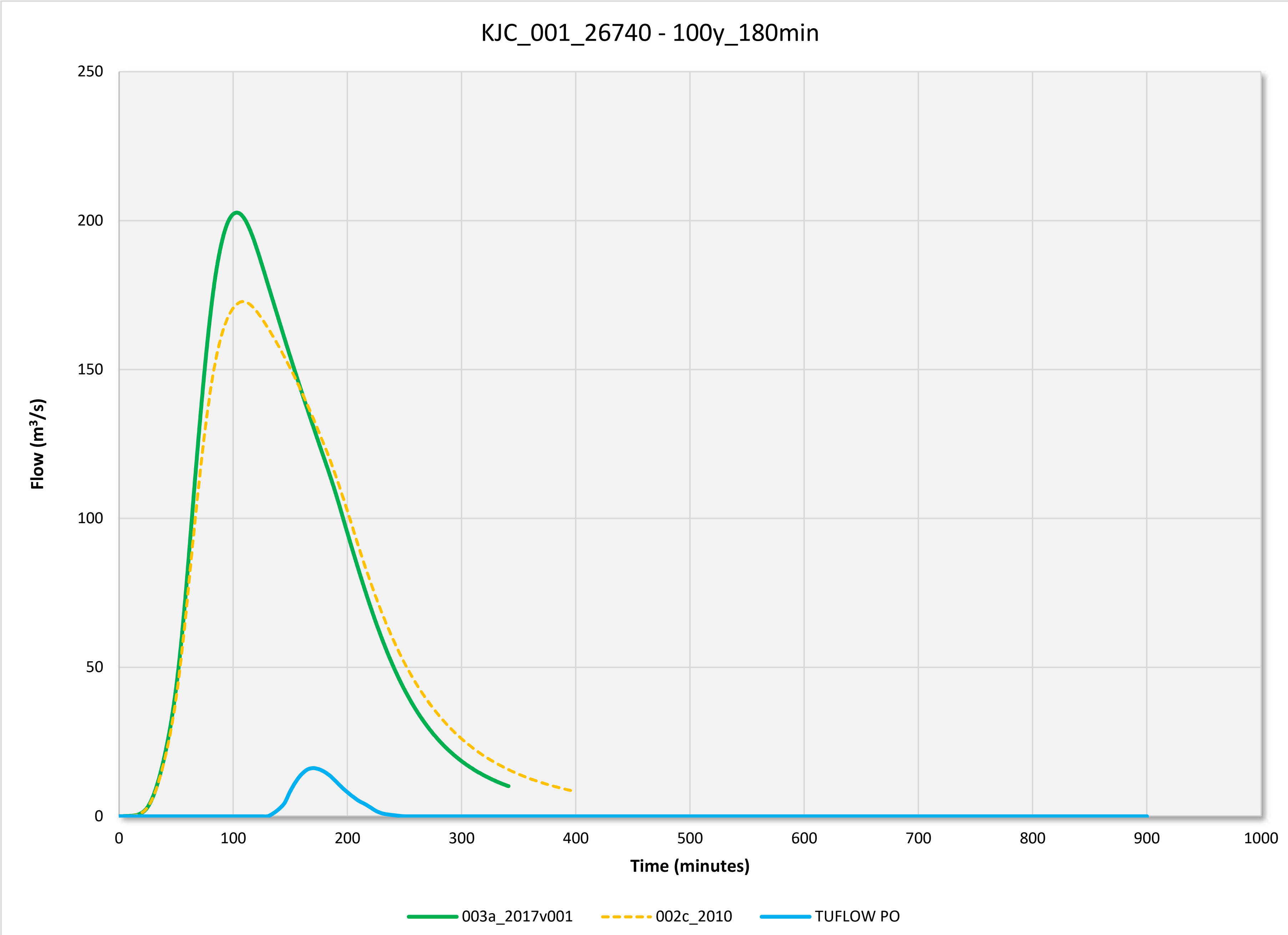
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO



KJC_001_26740 - 100y_180min
Flow (m³/s)
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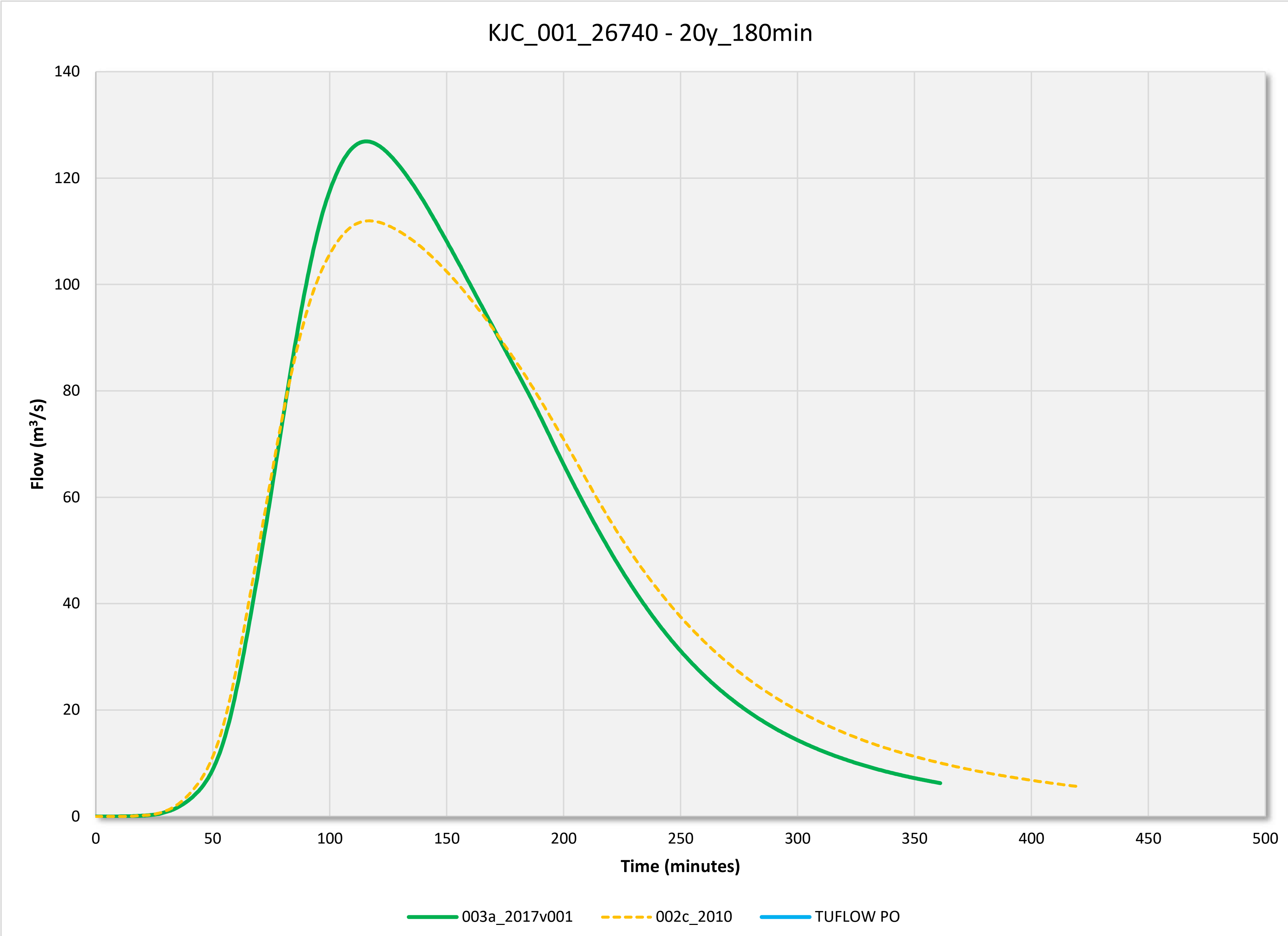
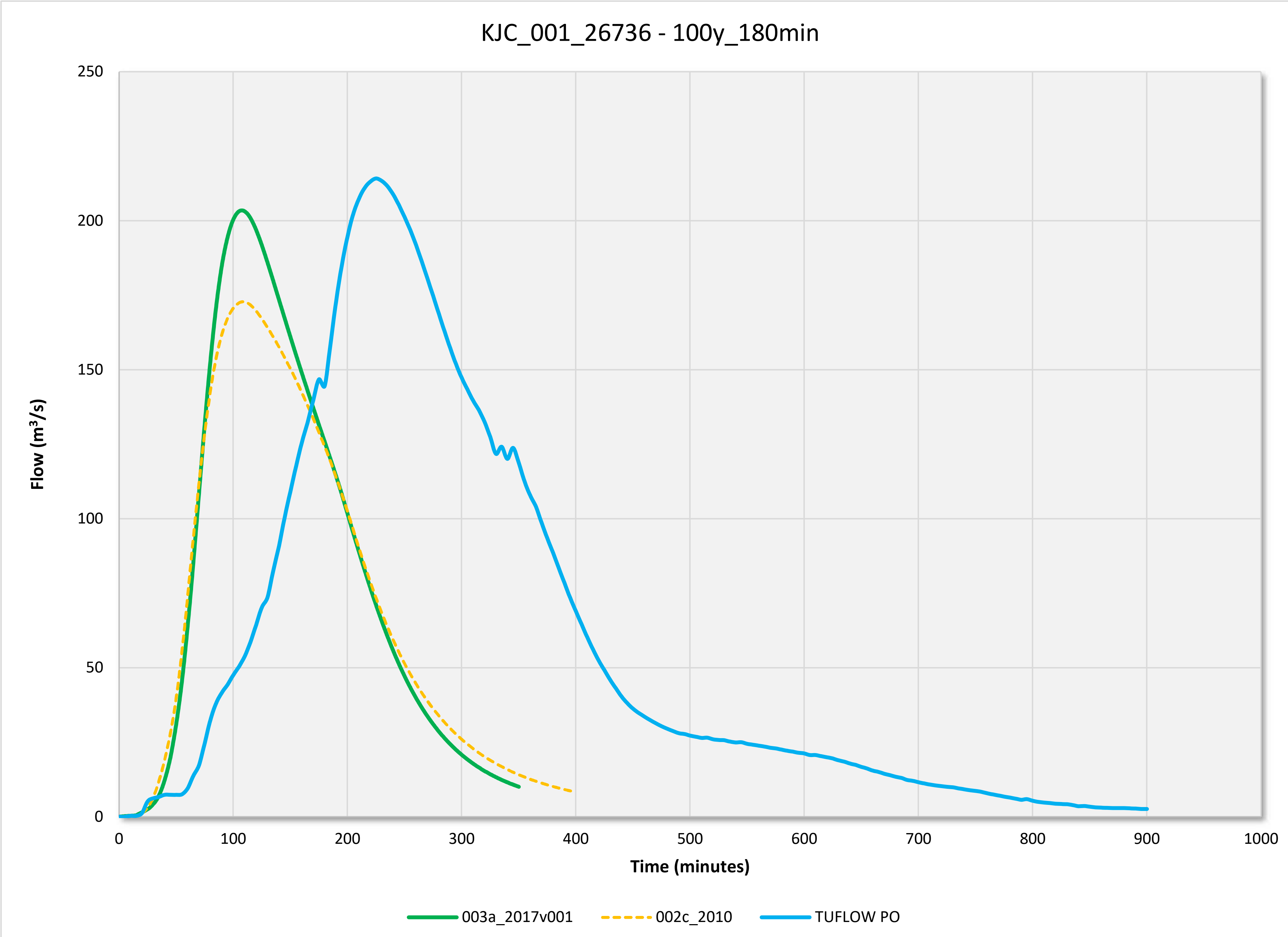
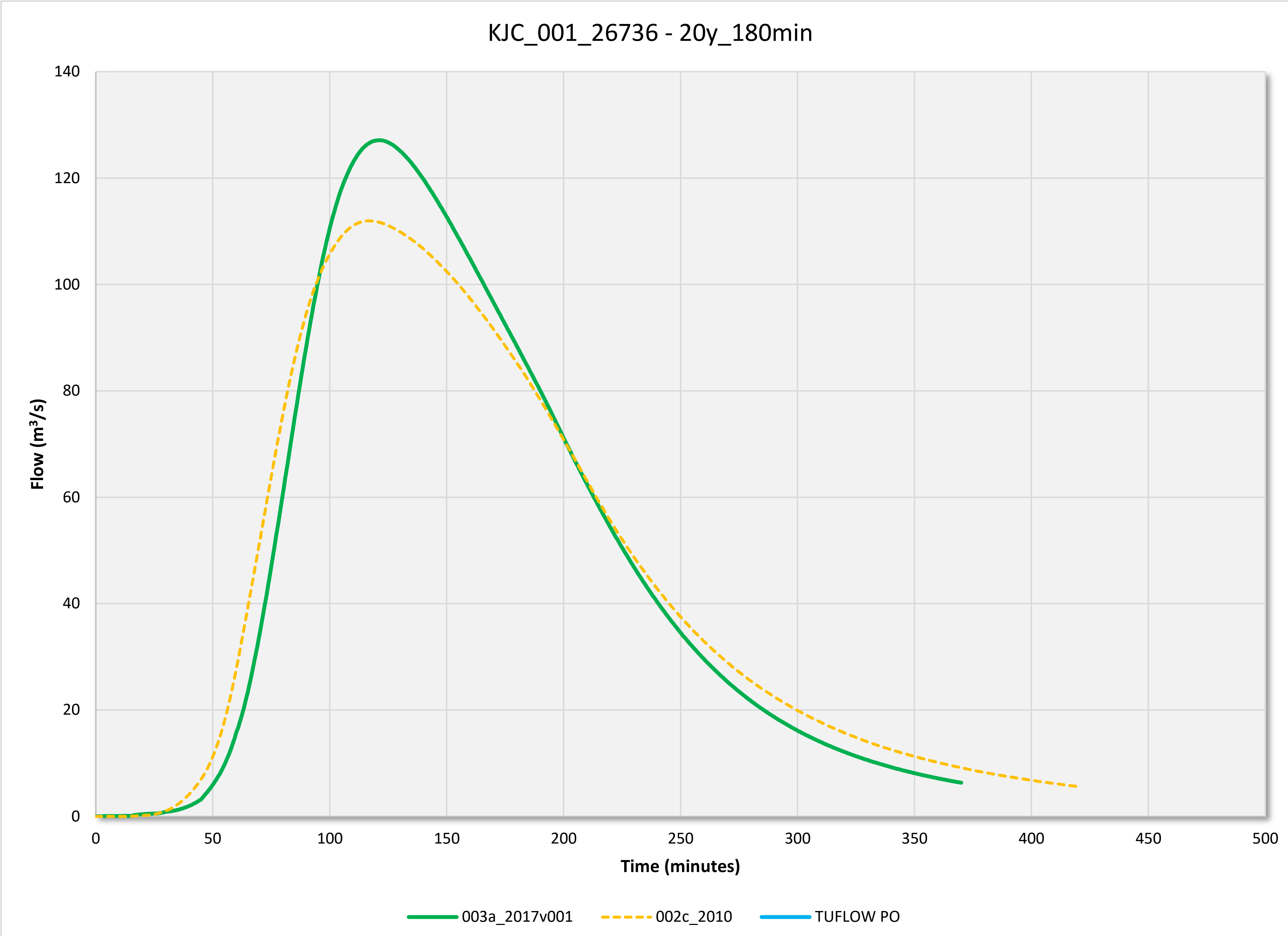
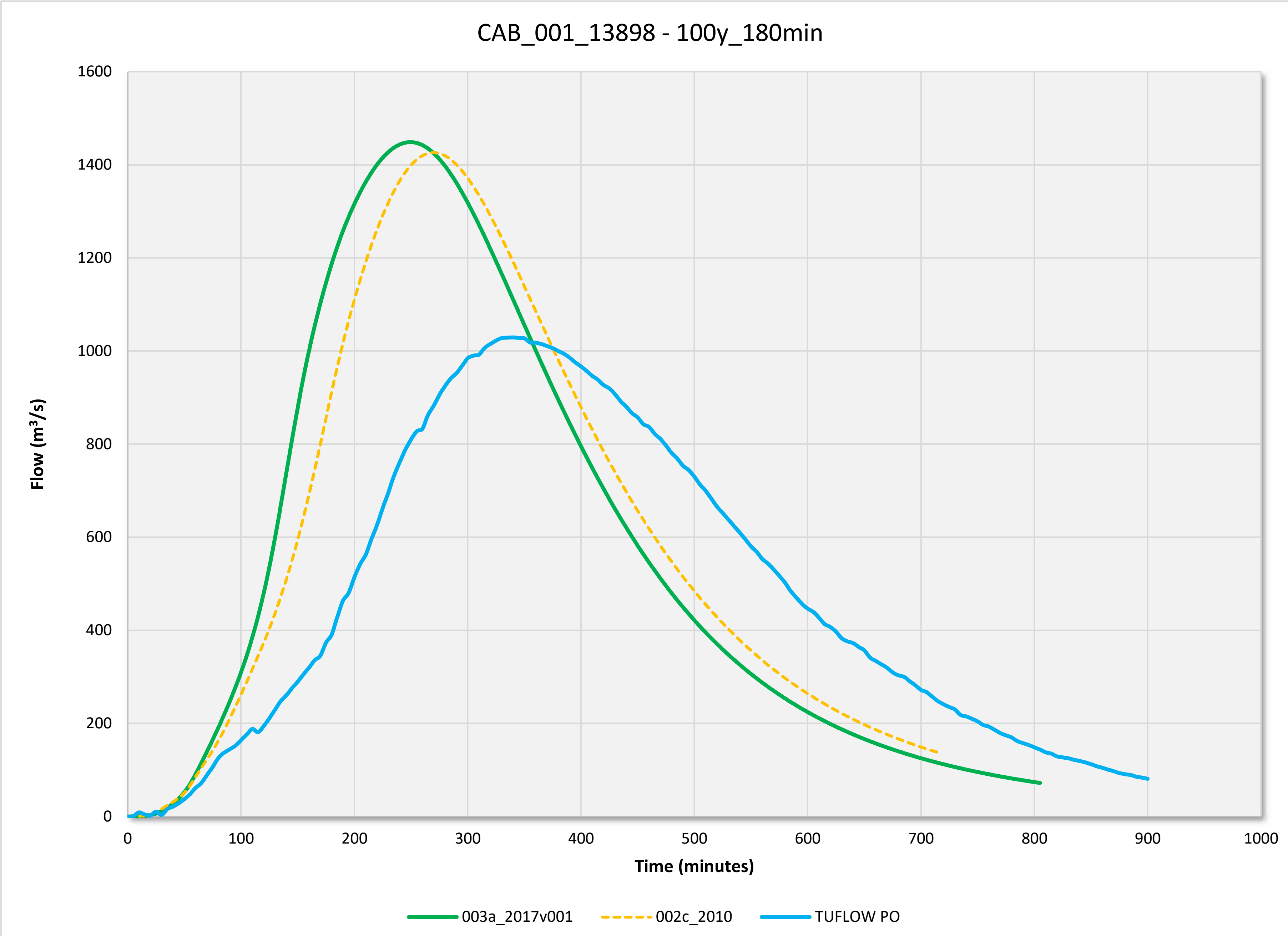
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



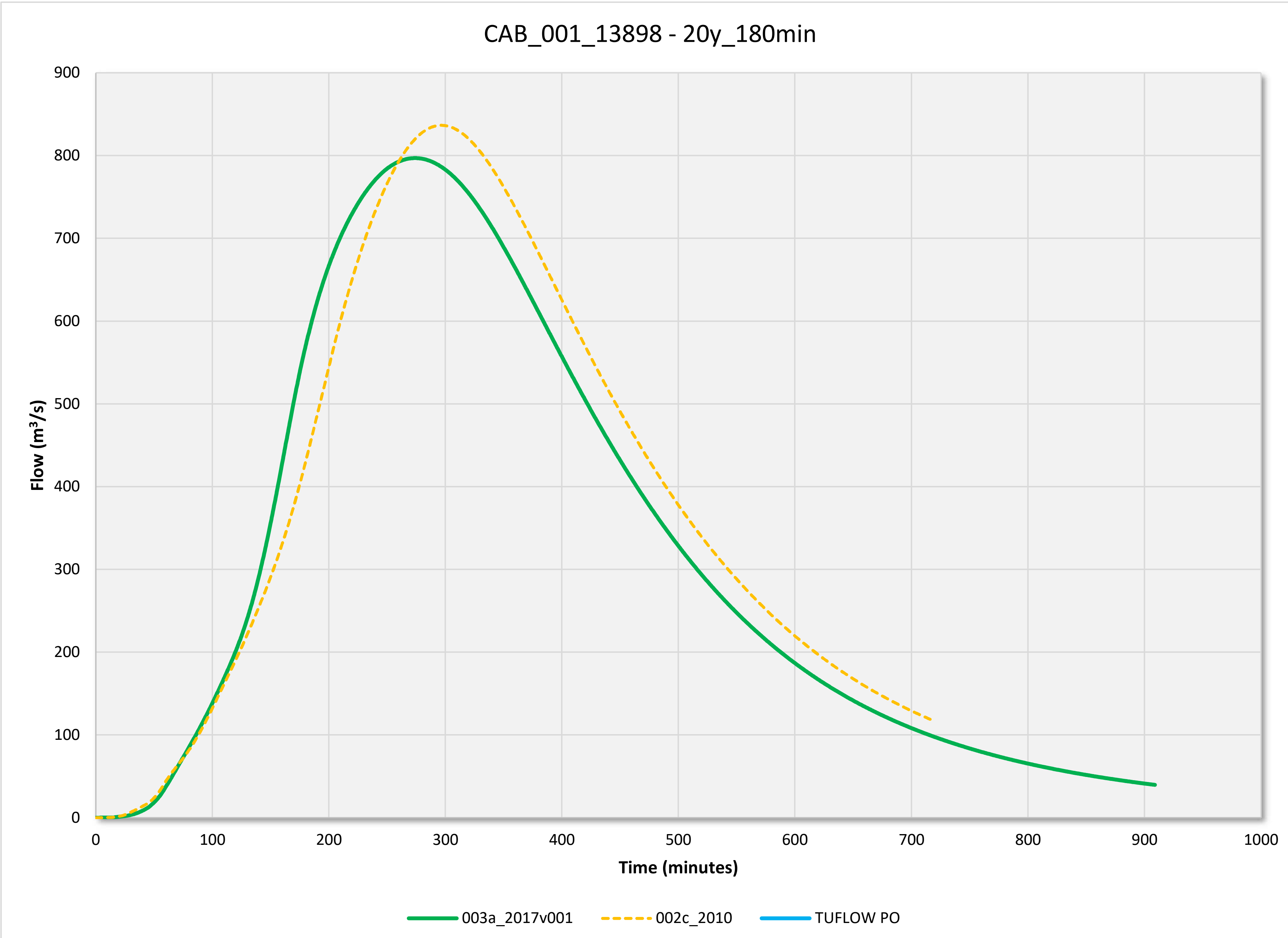
KJC_001_26740 - 20y_180min
Flow (m³/s)
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


KJC_001_26736 - 100y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

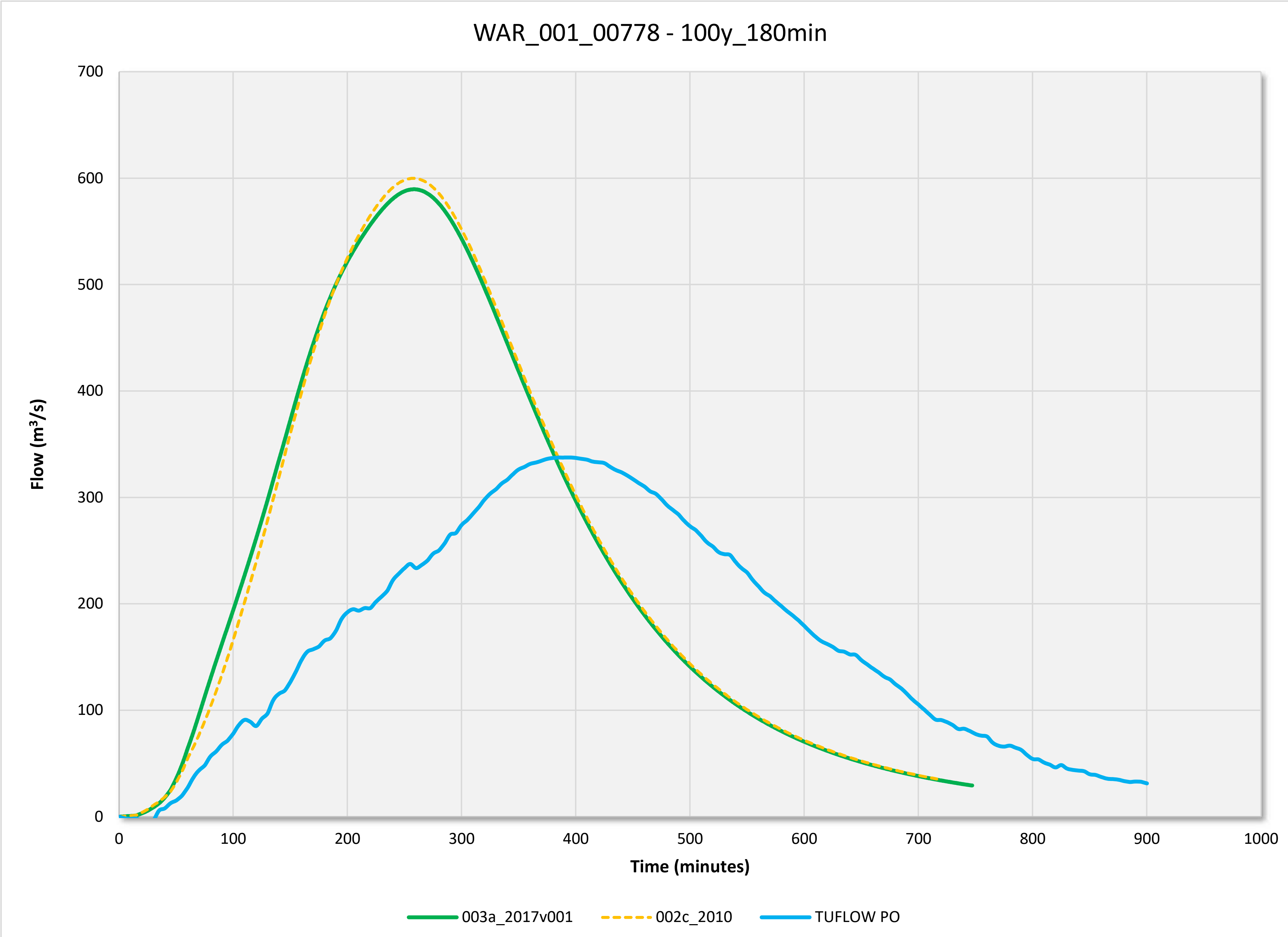

KJC_001_26736 - 20y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
500
003a_2017v001
002c_2010
TUFLOW PO



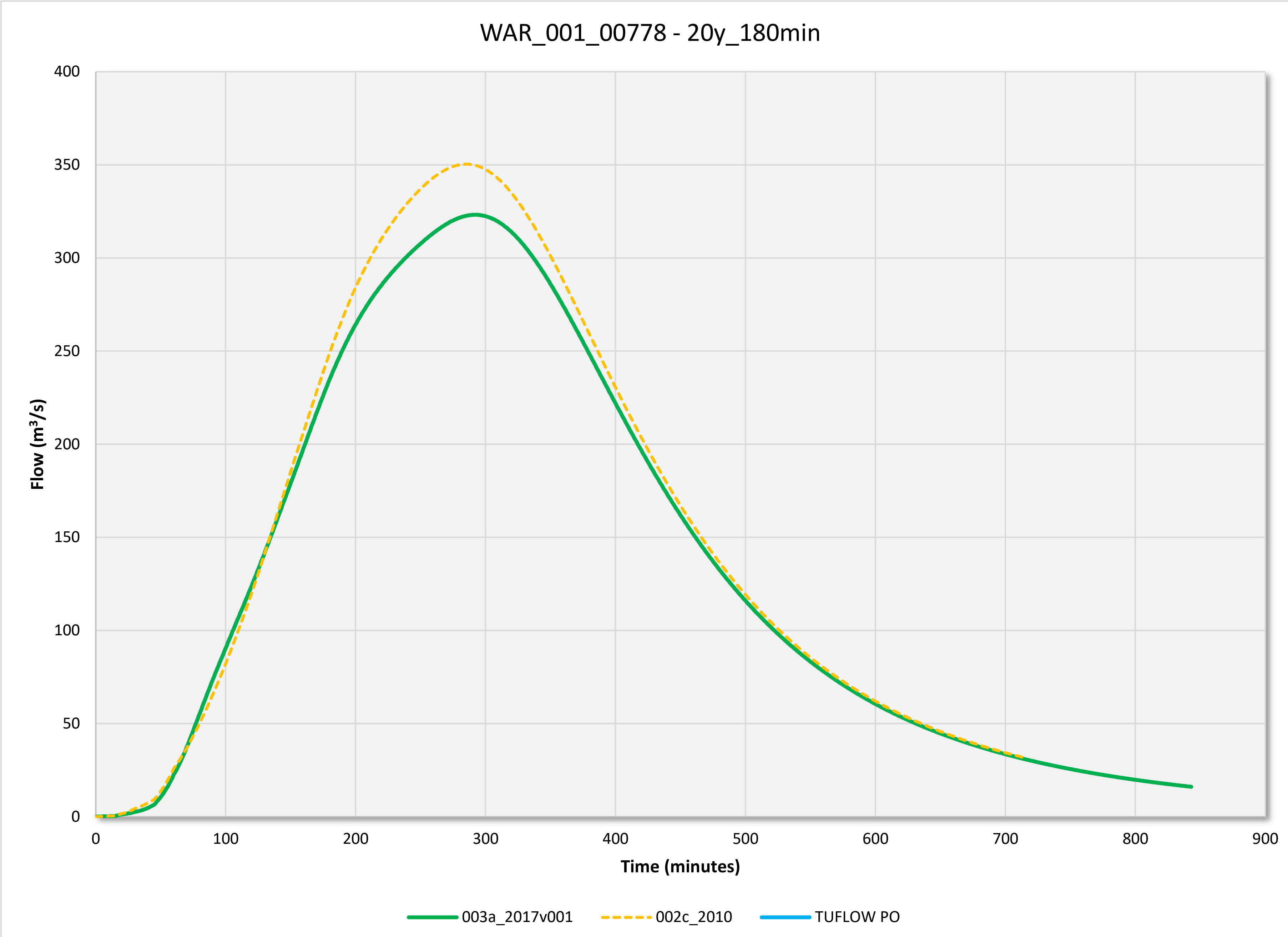
CAB_001_13898 - 100y_180min
Flow (m³/s)
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



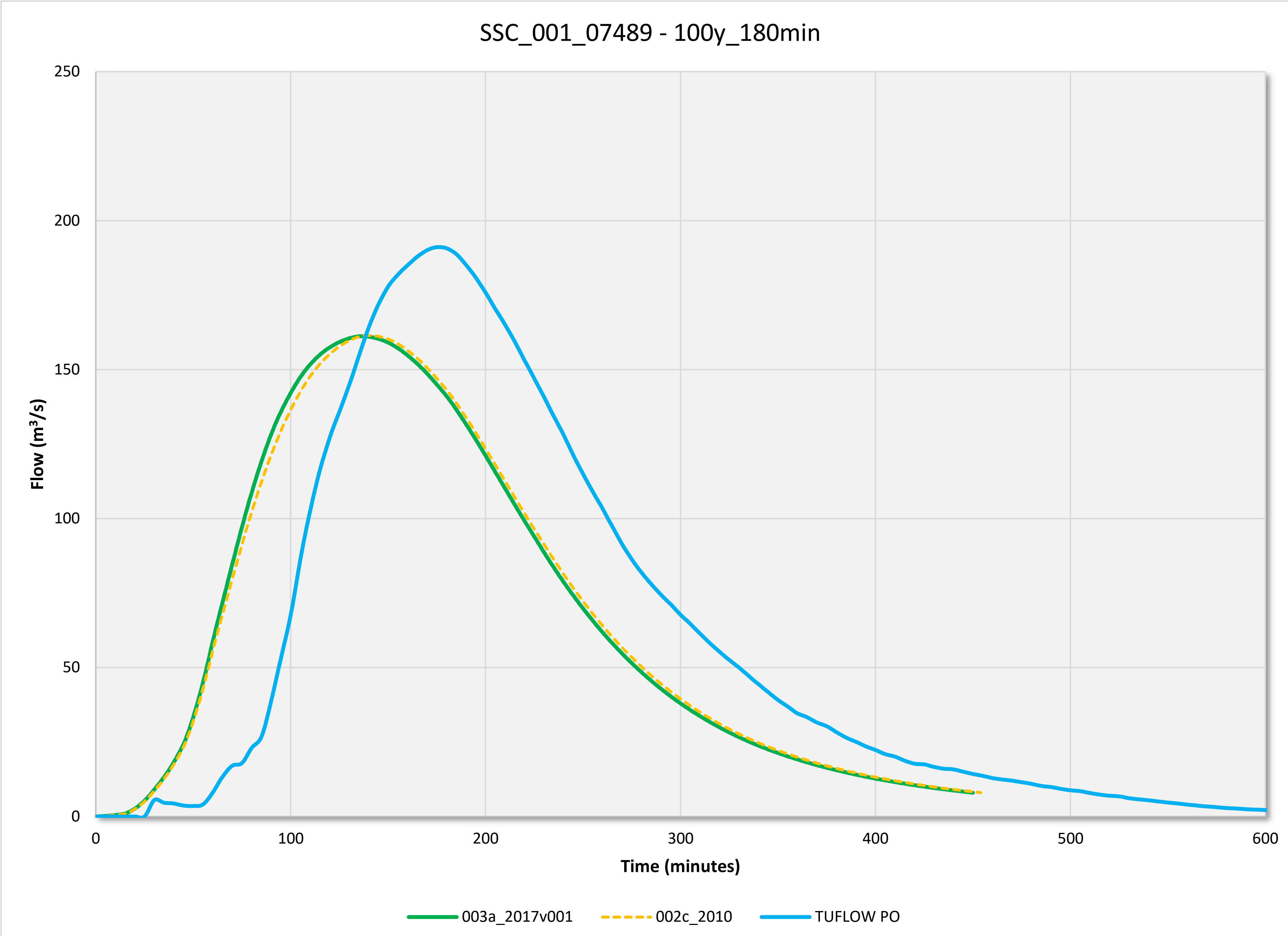
CAB_001_13898 - 20y_180min
Flow (m³/s)
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



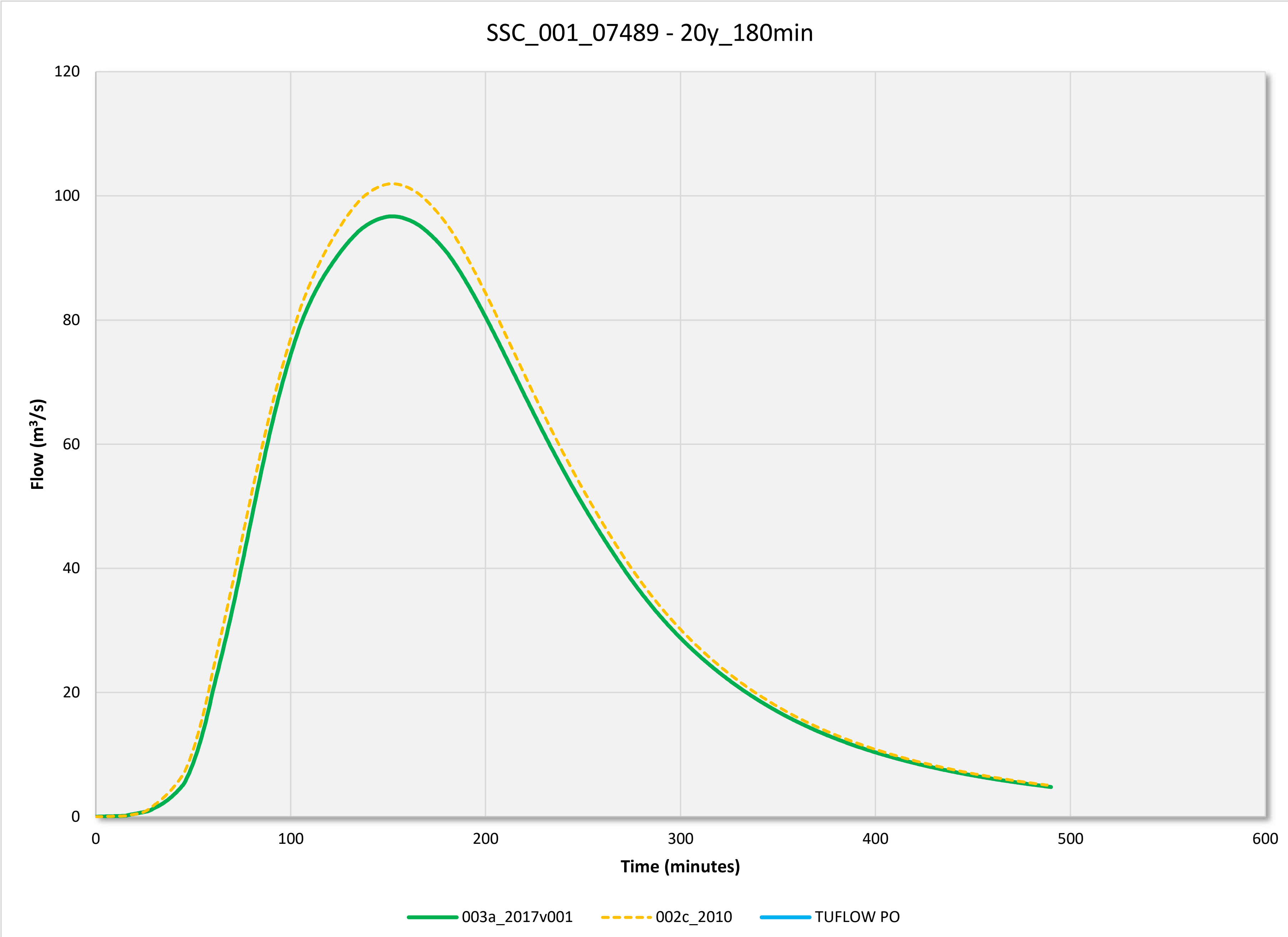
WAR_001_00778 - 100y_180min
Flow (m³/s)
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

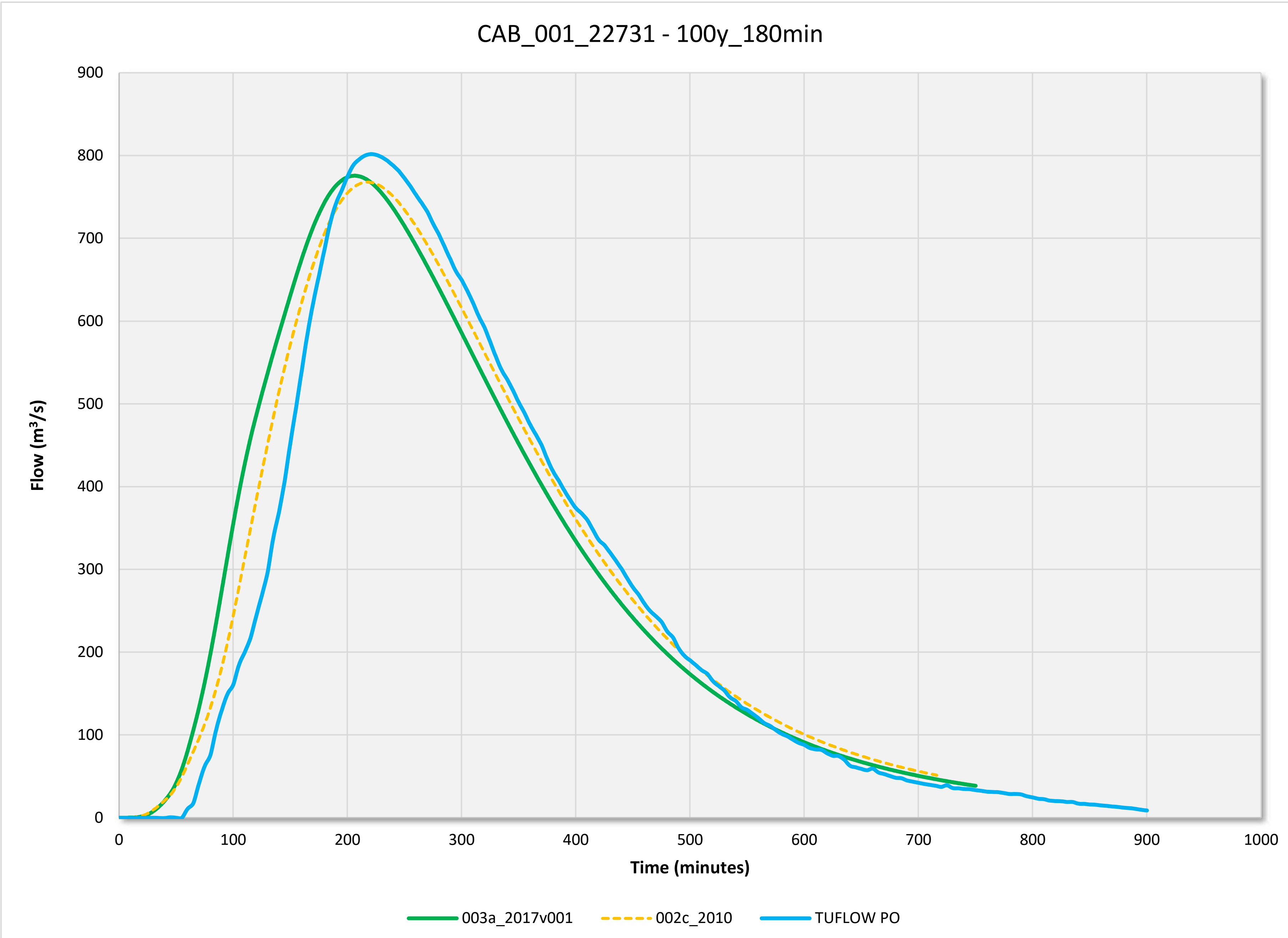


WAR_001_00778 - 20y_180min
Flow (m³/s)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

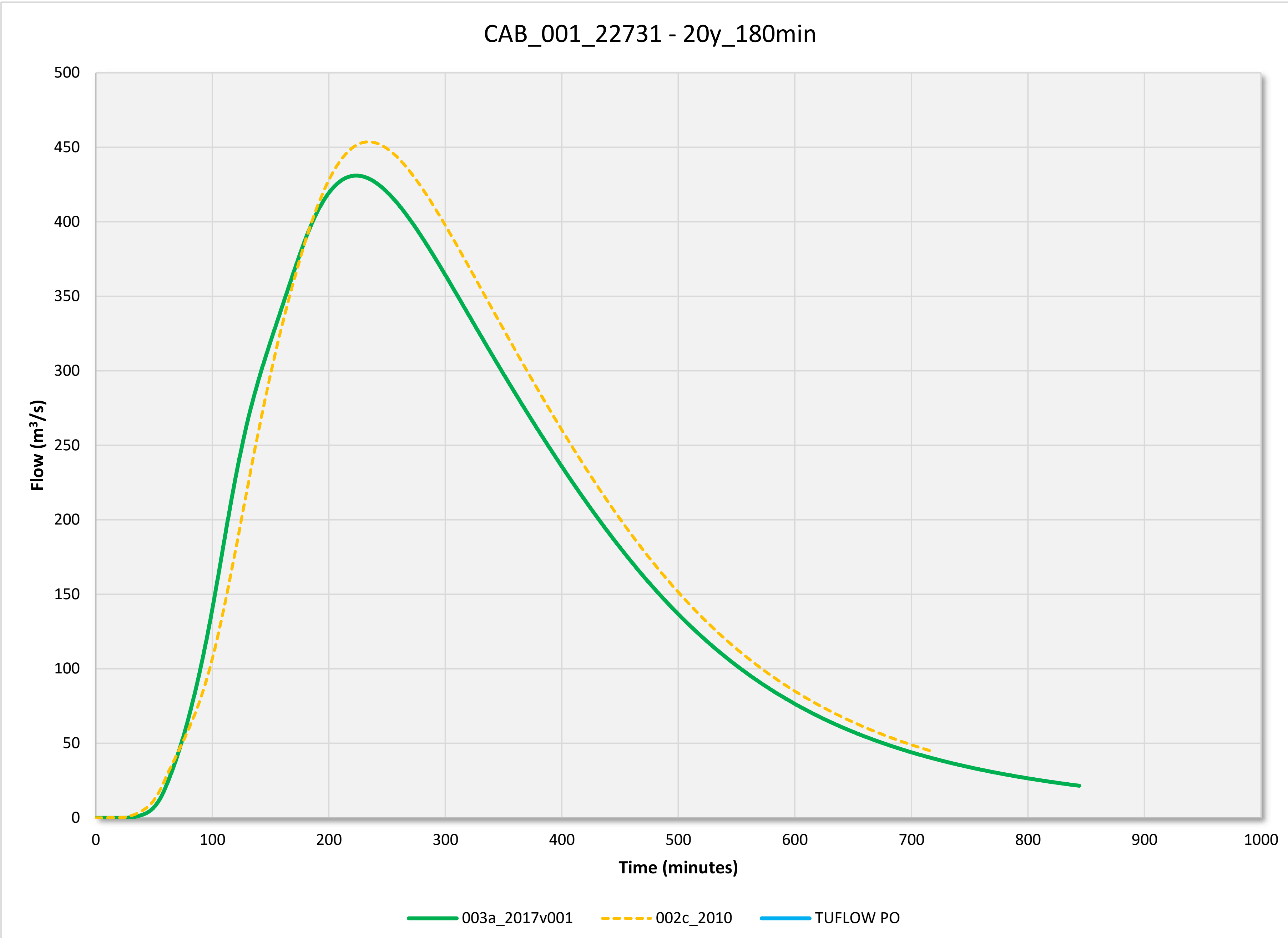


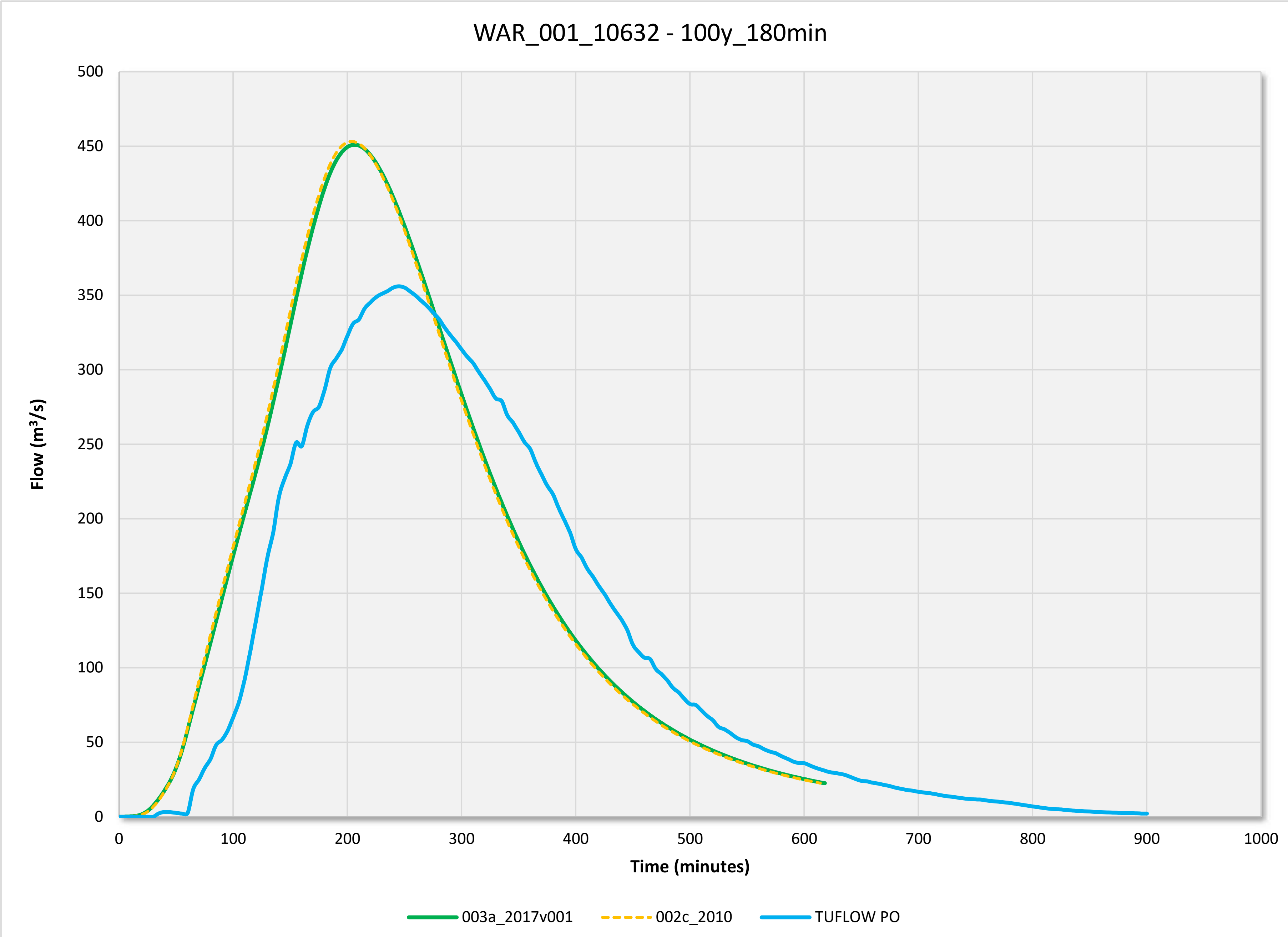
SSC_001_07489 - 100y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

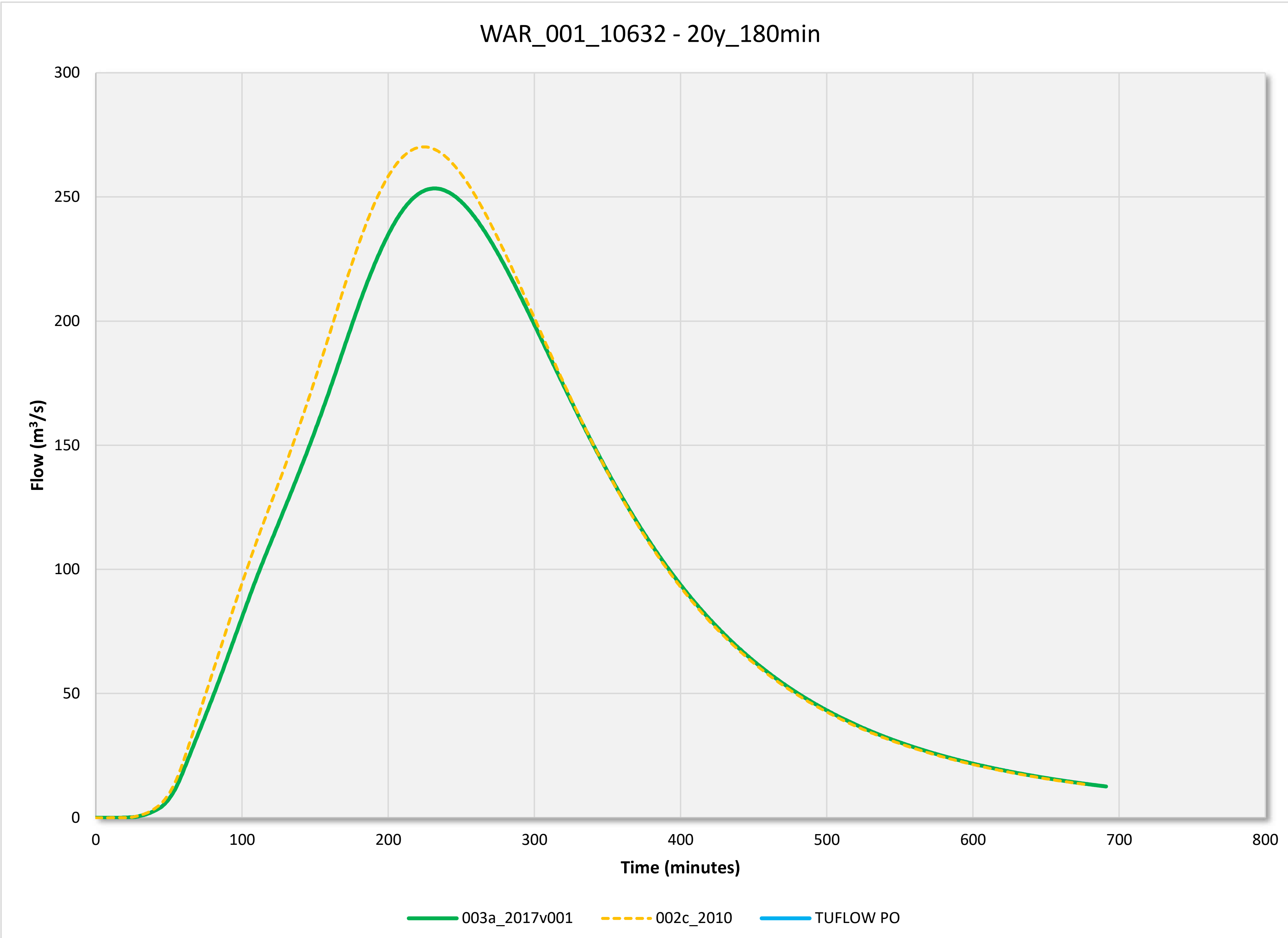

SSC_001_07489 - 20y_180min
Flow (m³/s)
120
100
80
60
40
20
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



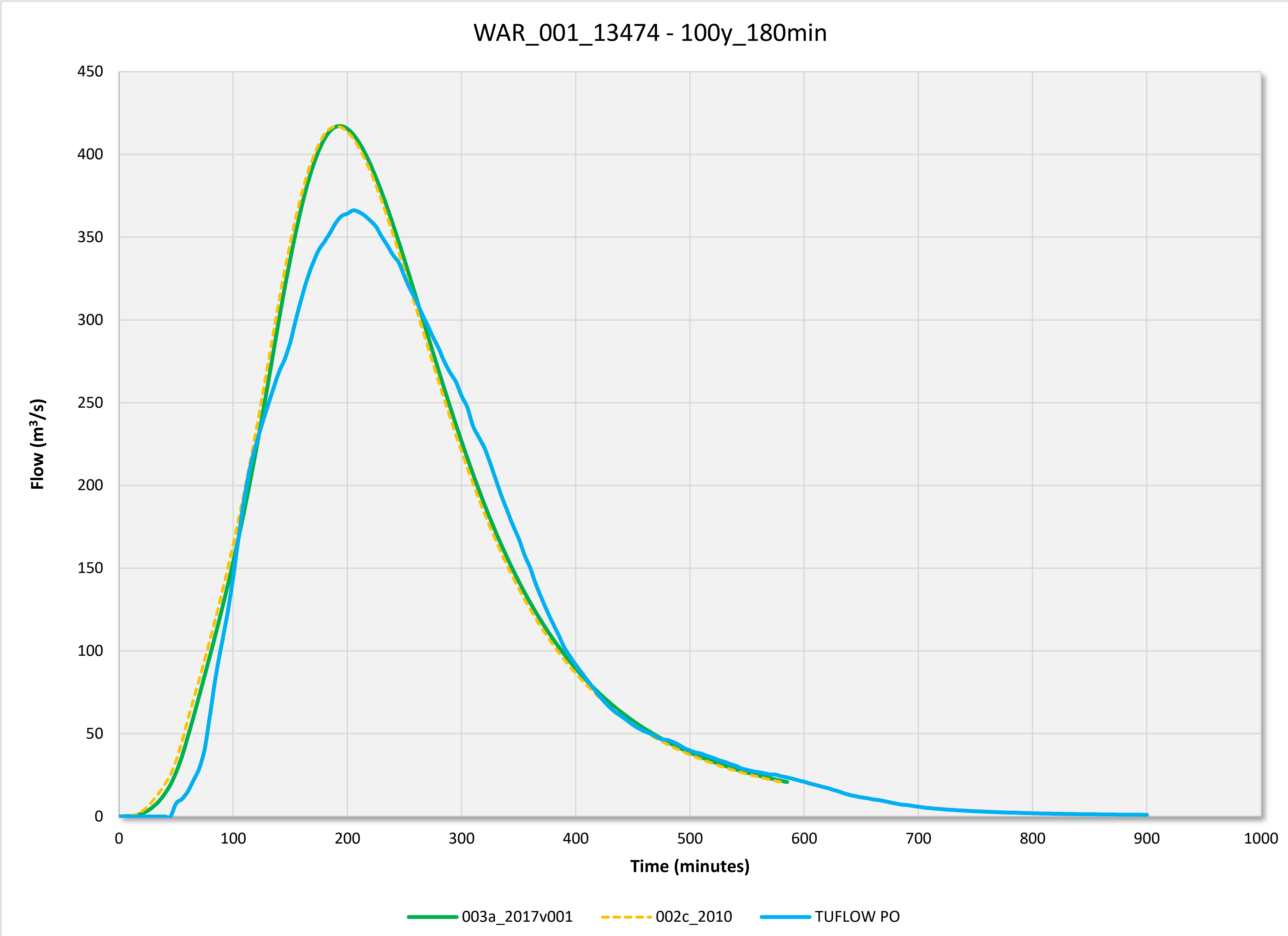
CAB_001_22731 - 100y_180min
Flow (m³/s)
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

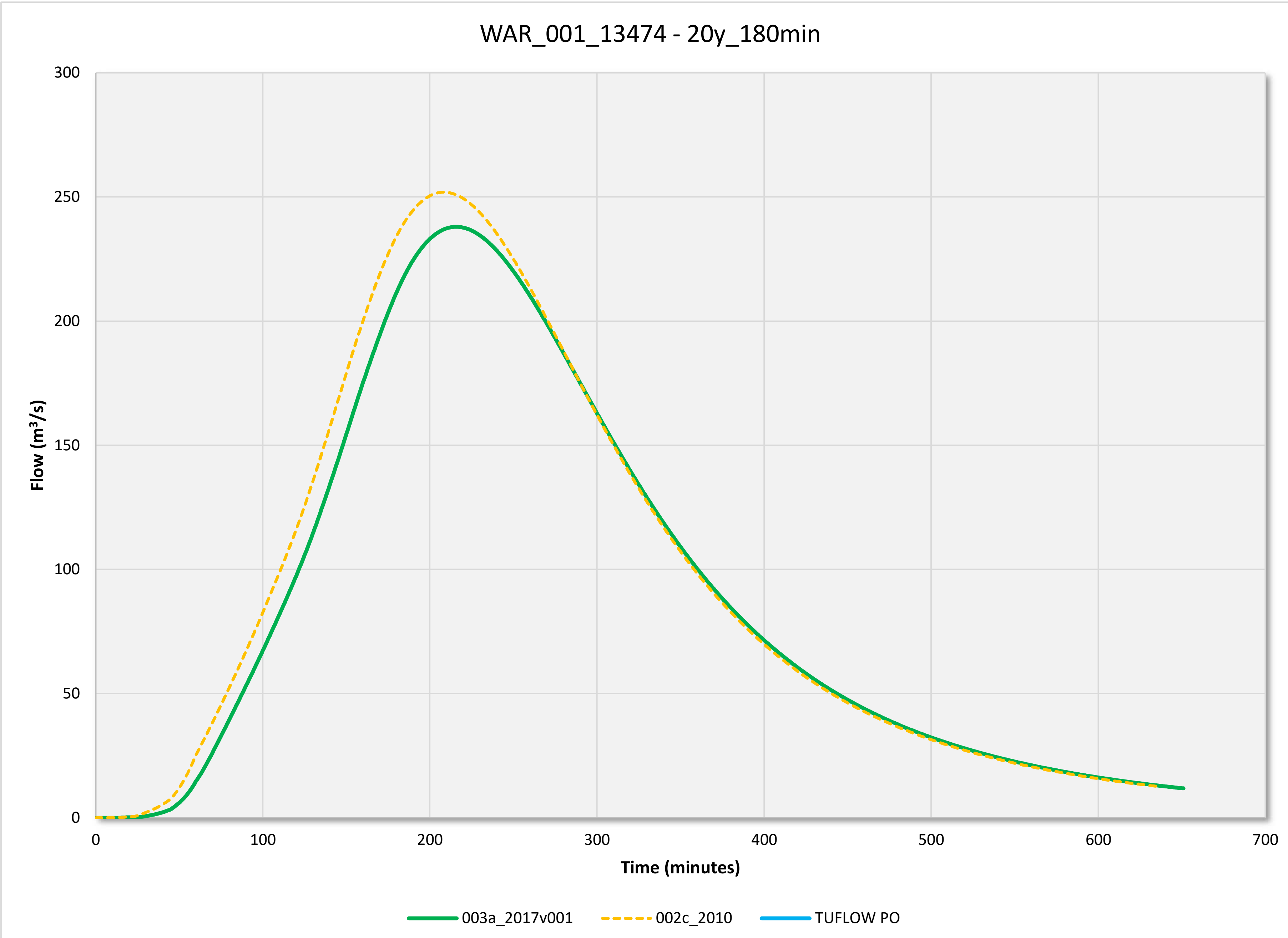

CAB_001_22731 - 20y_180min
Flow (m³/s)
0
50
100
150
200
250
300
350
400
450
500
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
003a_2017v001
002c_2010
TUFLOW PO

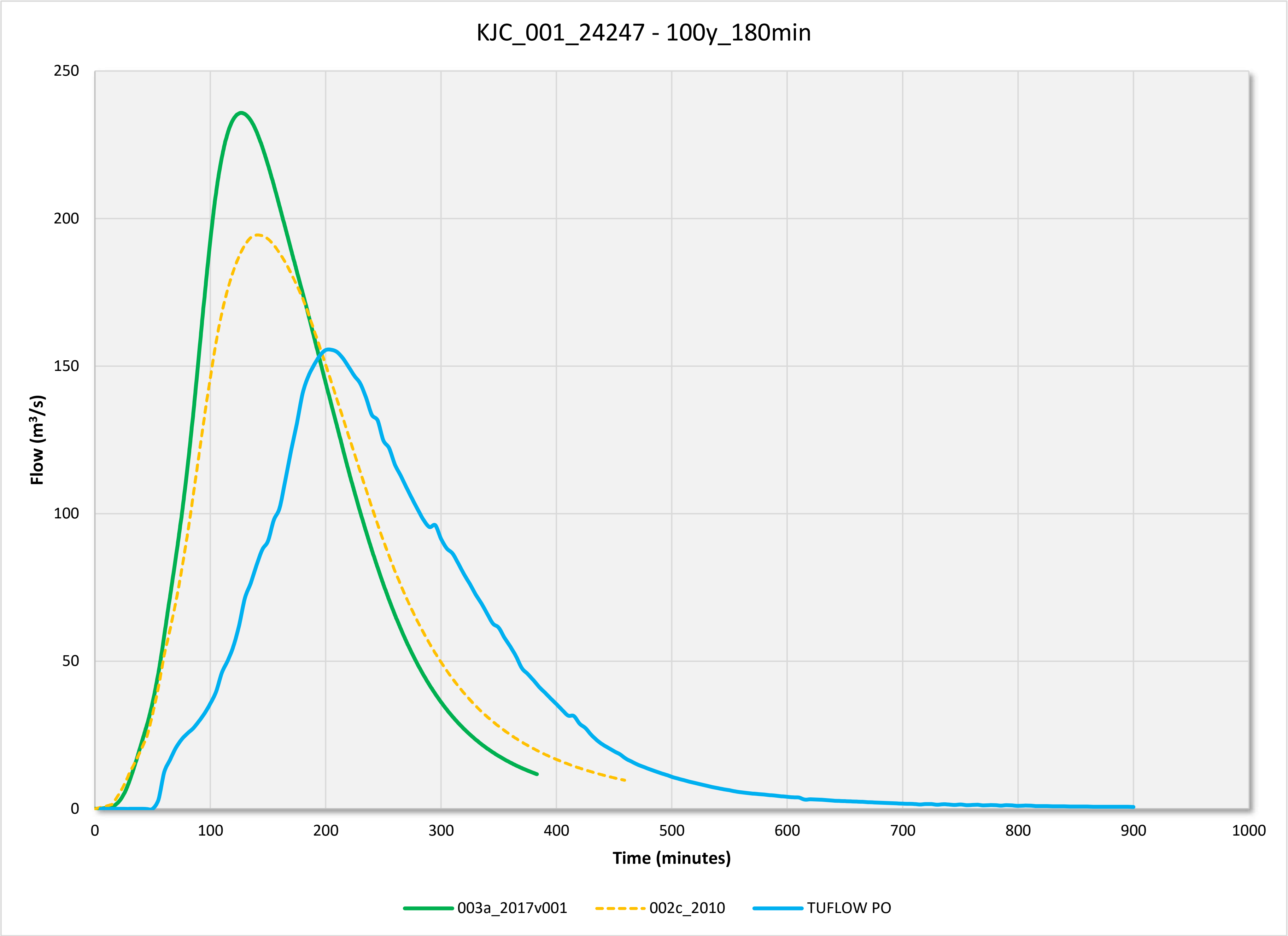

WAR_001_10632 - 100y_180min
Flow (m³/s)
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

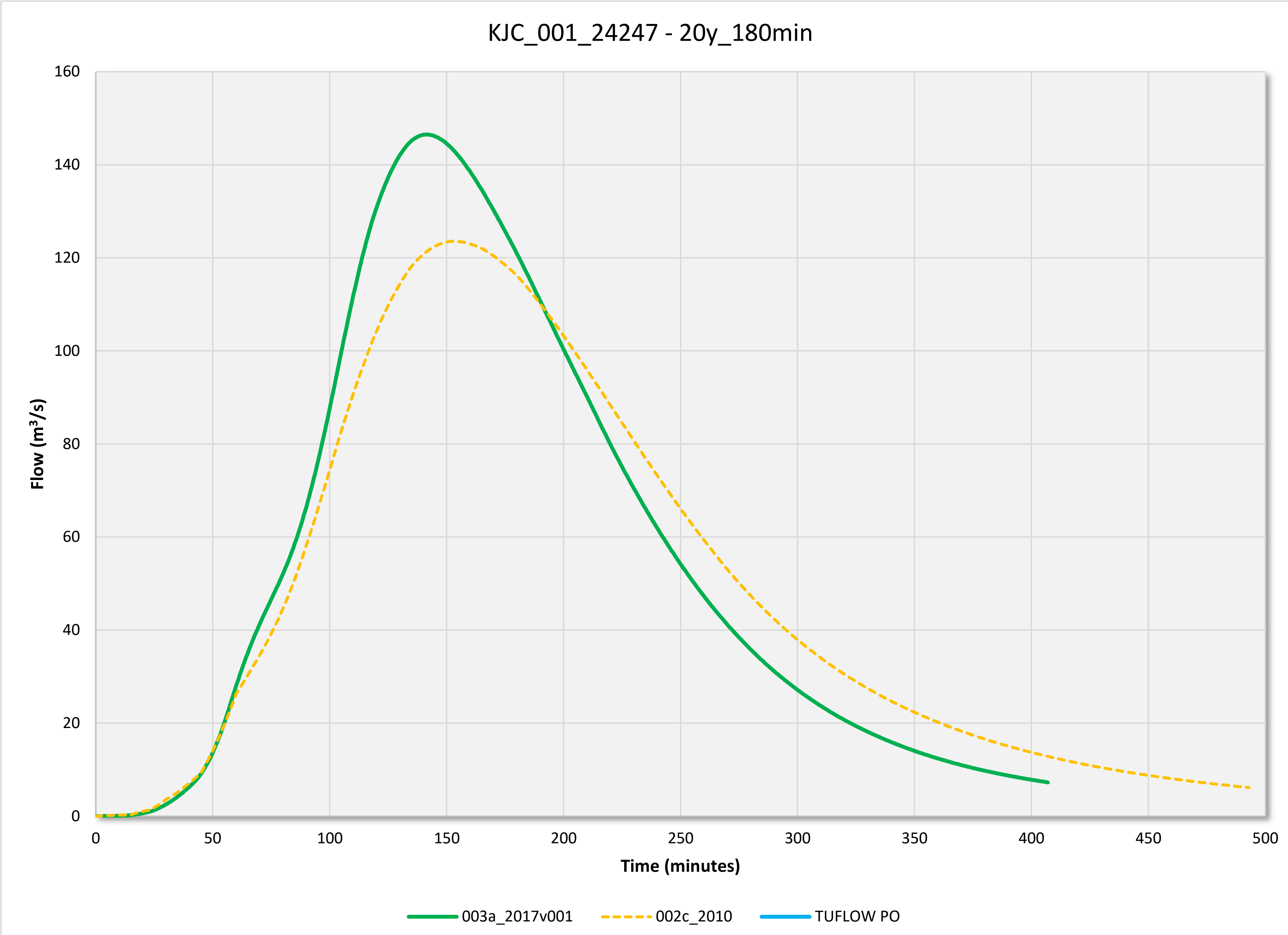


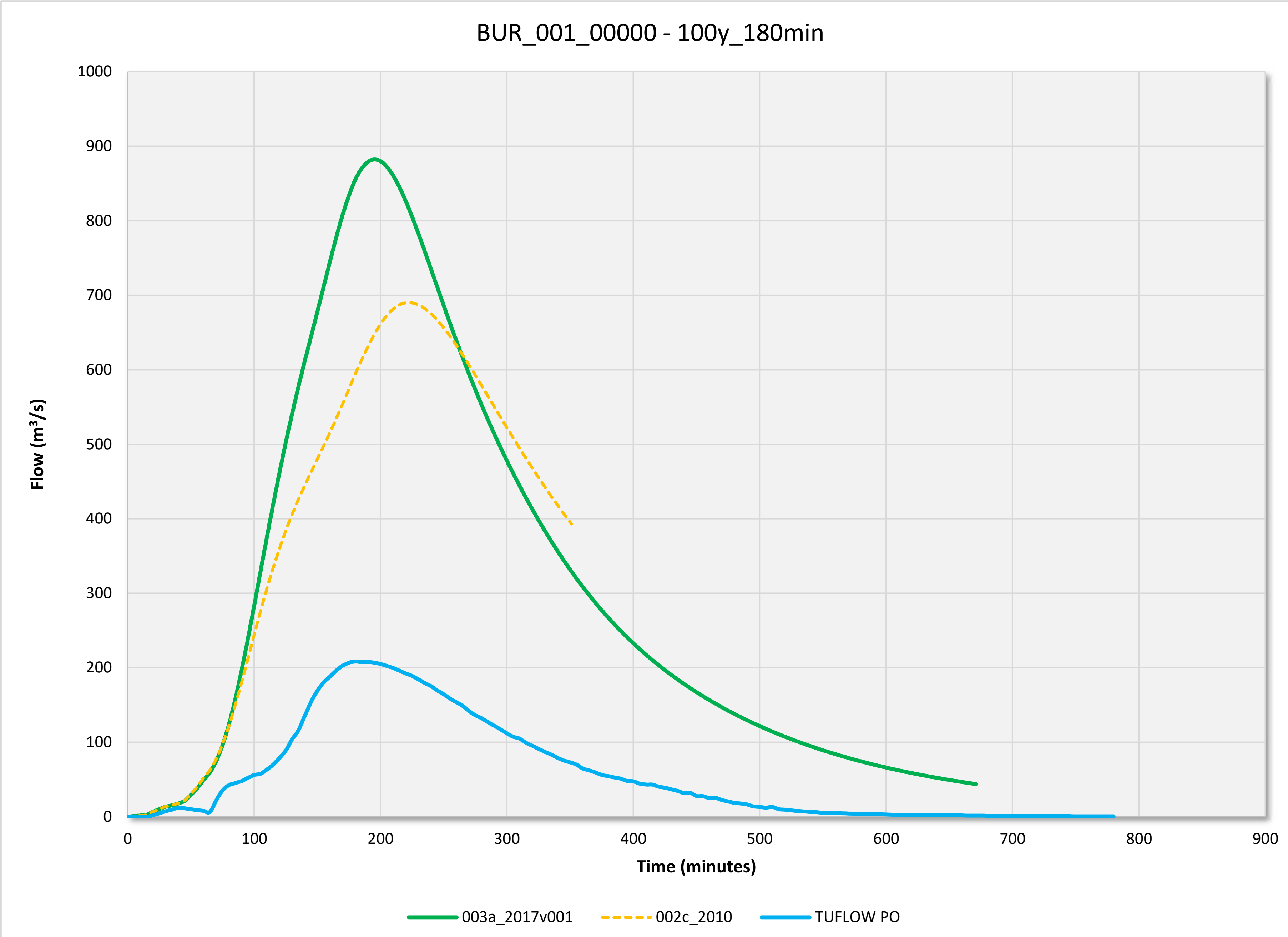
WAR_001_10632 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

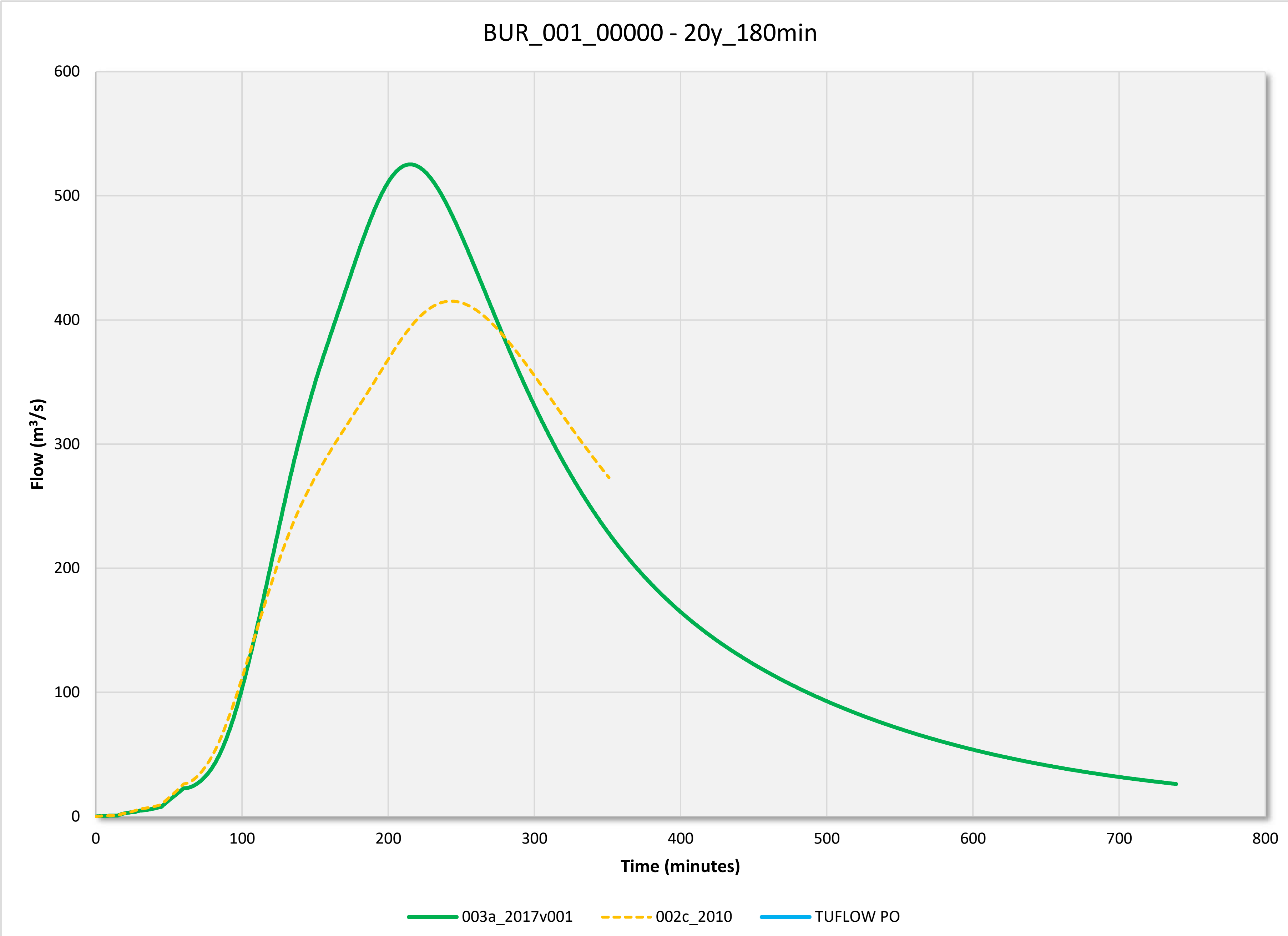

WAR_001_13474 - 100y_180min
Flow (m³/s)
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

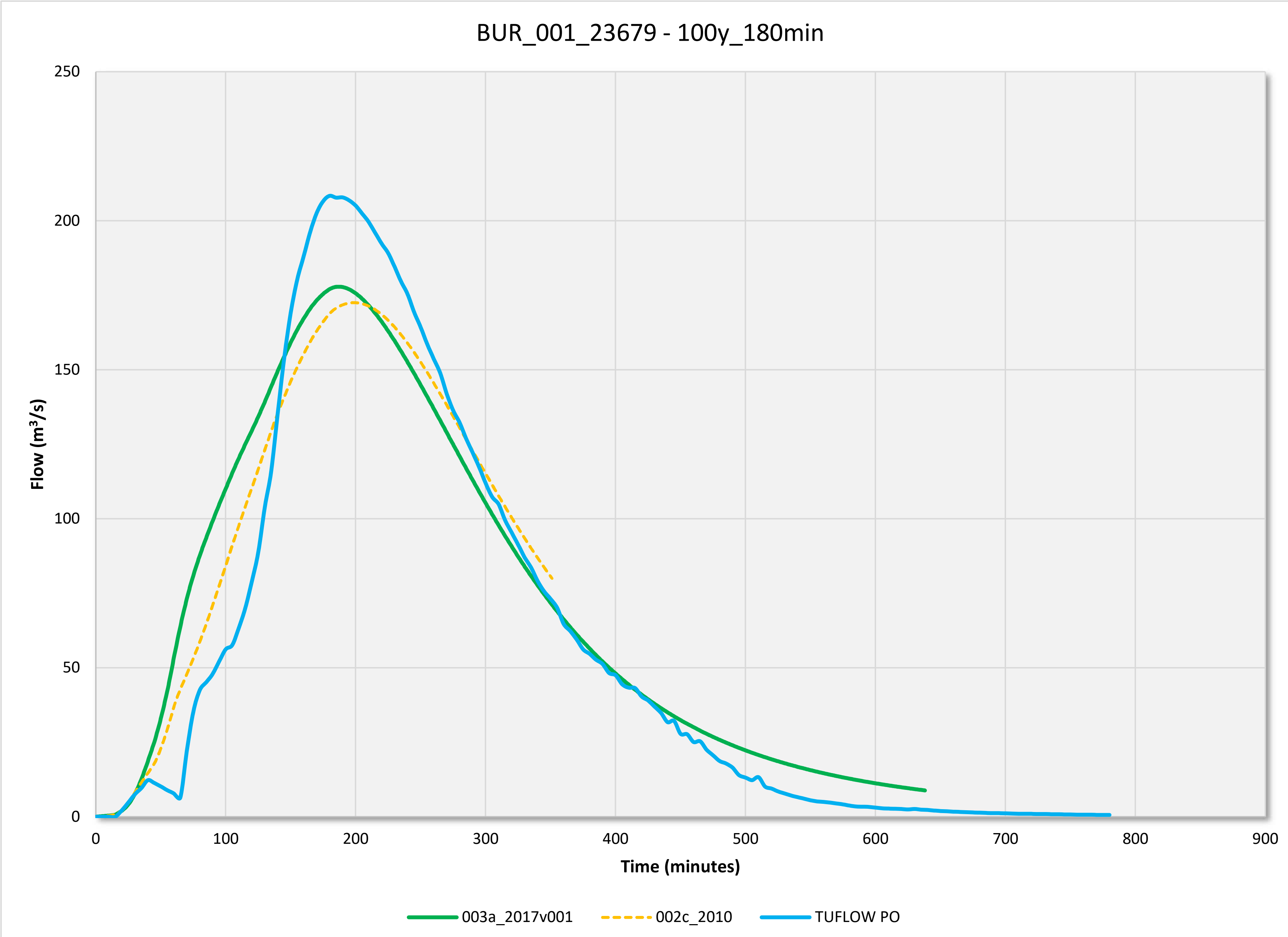

WAR_001_13474 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


KJC_001_24247 - 100y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

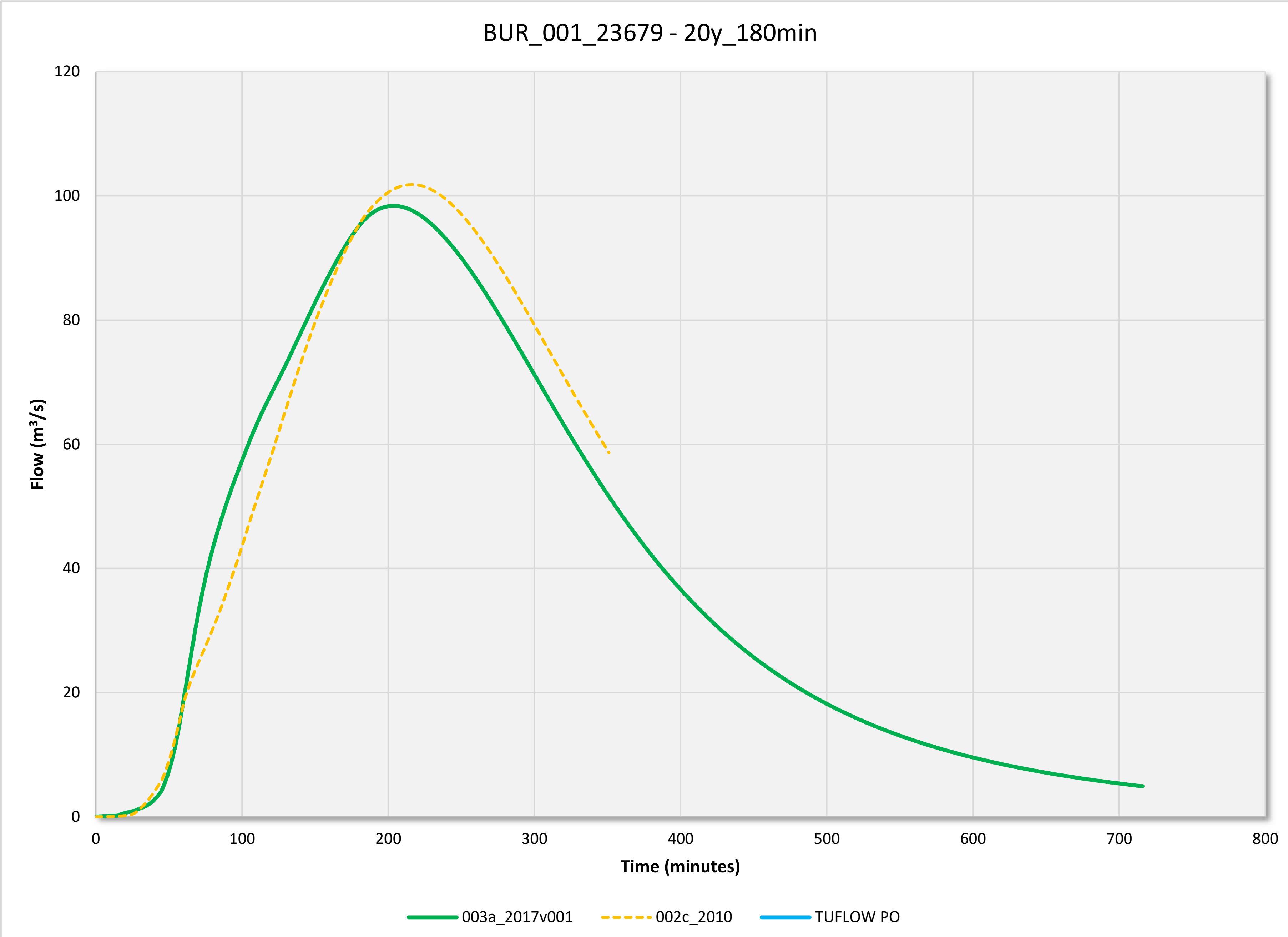

KJC_001_24247 - 20y_180min
Flow (m³/s)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

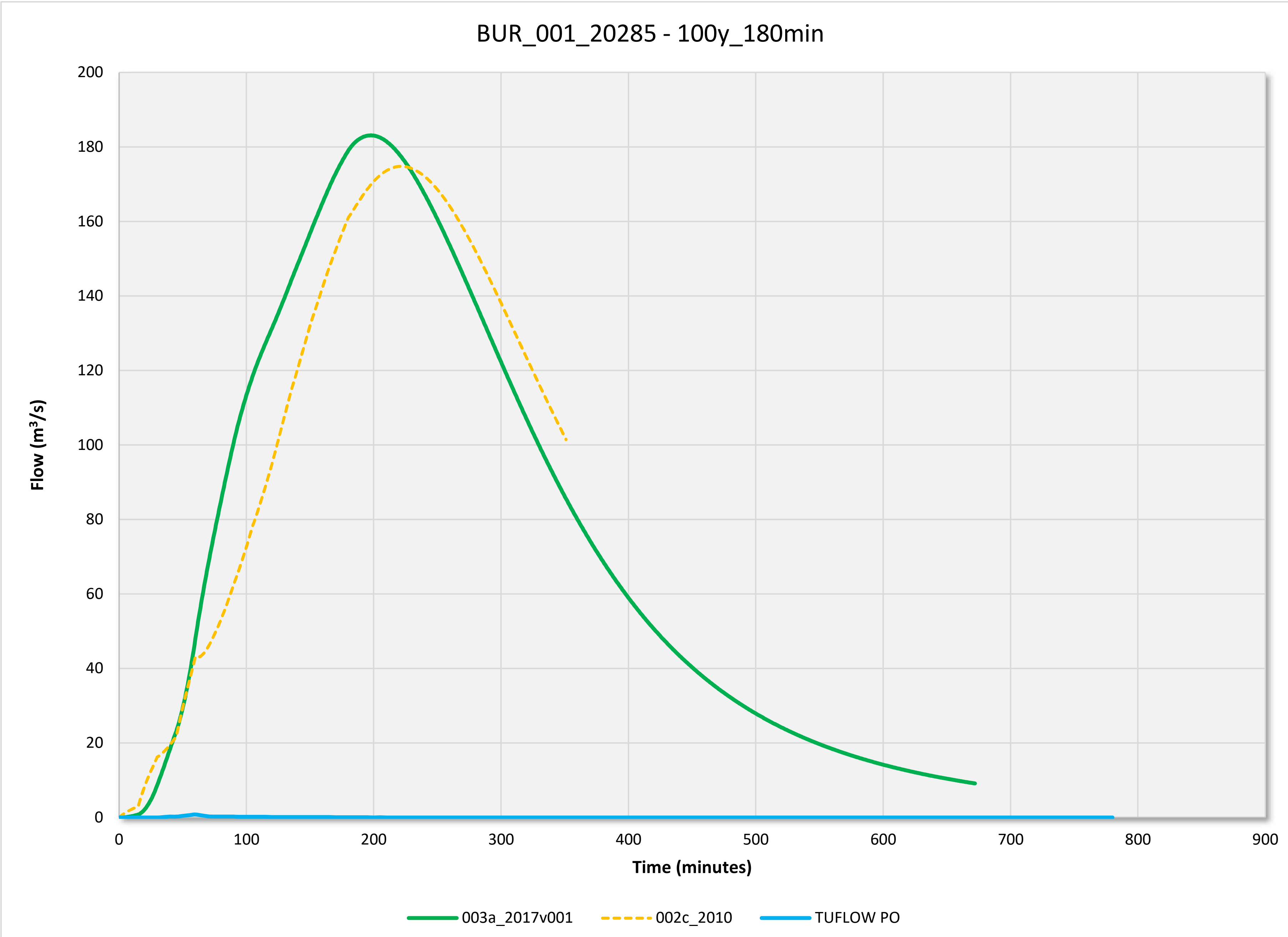

BUR_001_00000 - 100y_180min
Flow (m³/s)
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

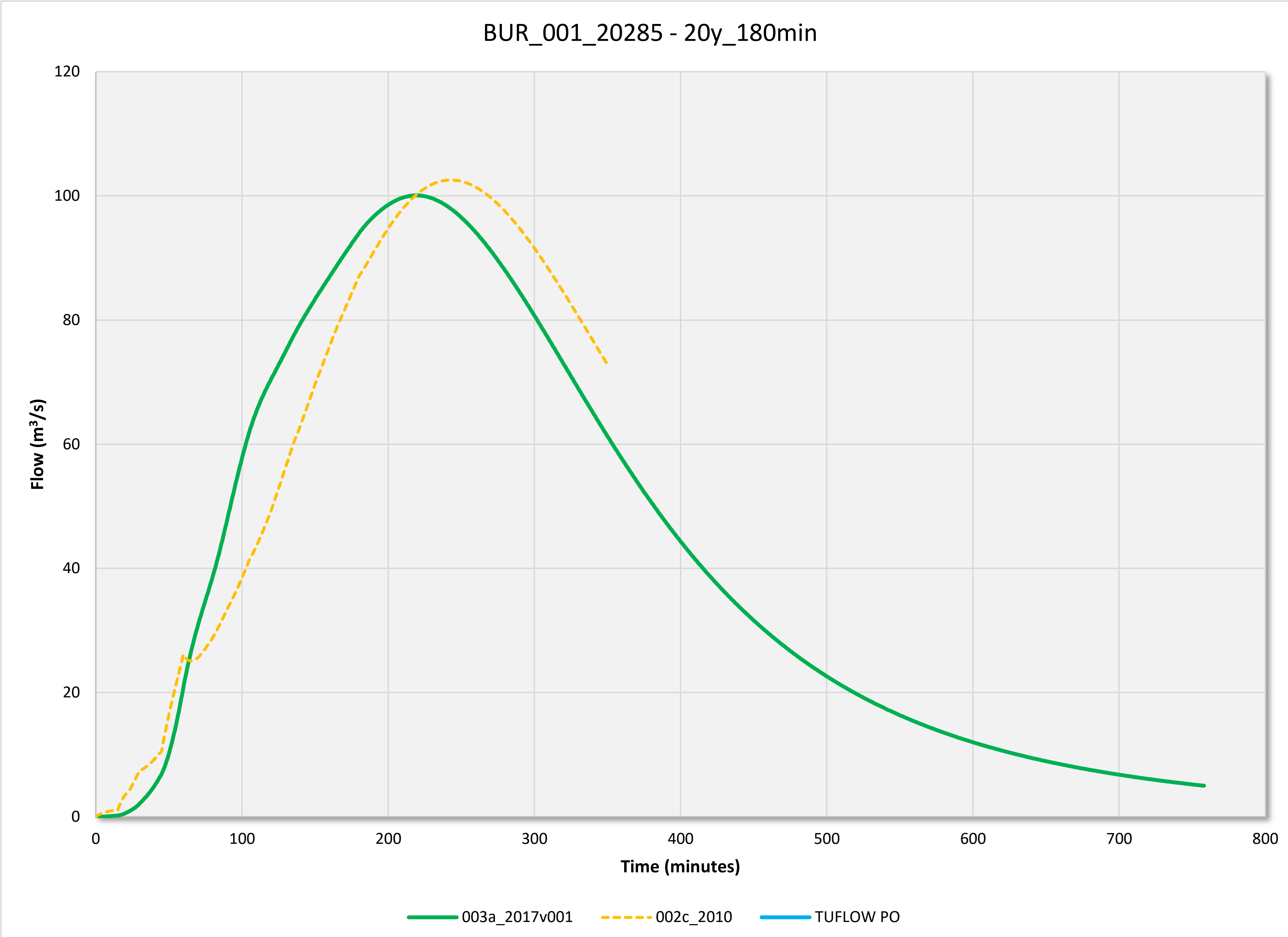

BUR_001_00000 - 20y_180min
Flow (m³/s)
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

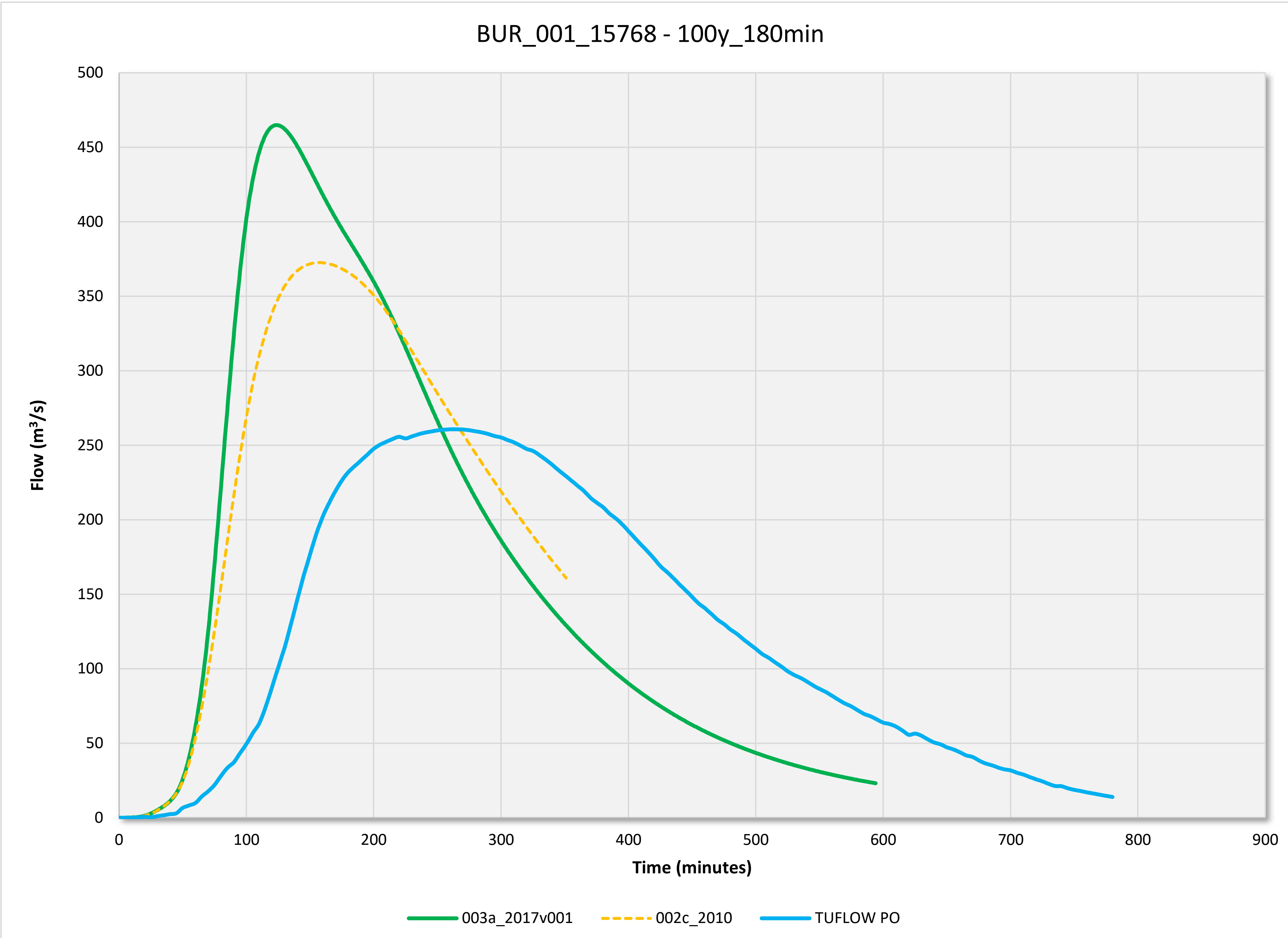


BUR_001_23679 - 100y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

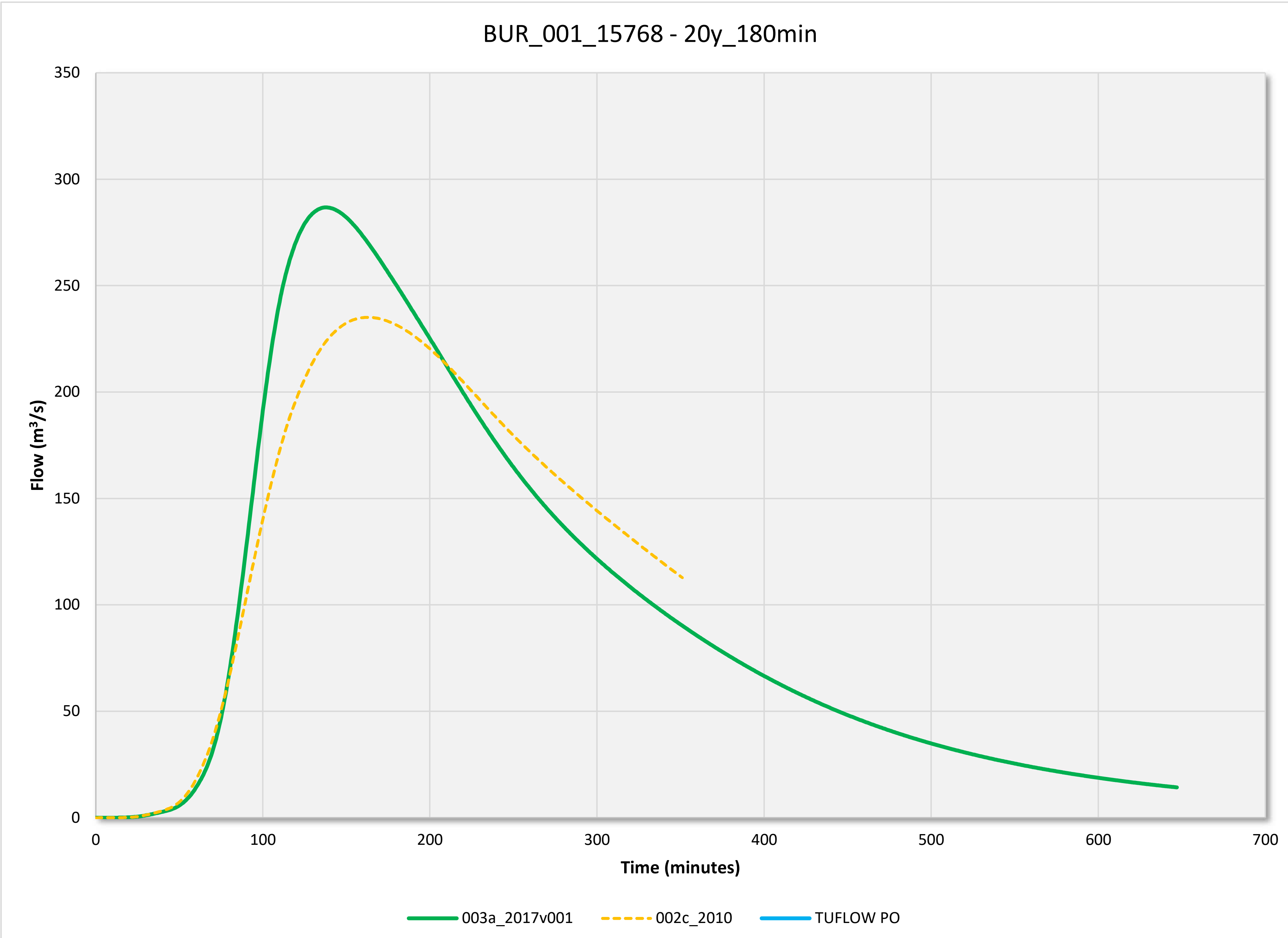

BUR_001_23679 - 20y_180min
120
100
80
60
40
20
0
Flow (m³/s)
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


BUR_001_20285 - 100y_180min
Flow (m³/s)
0
20
40
60
80
100
120
140
160
180
200
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

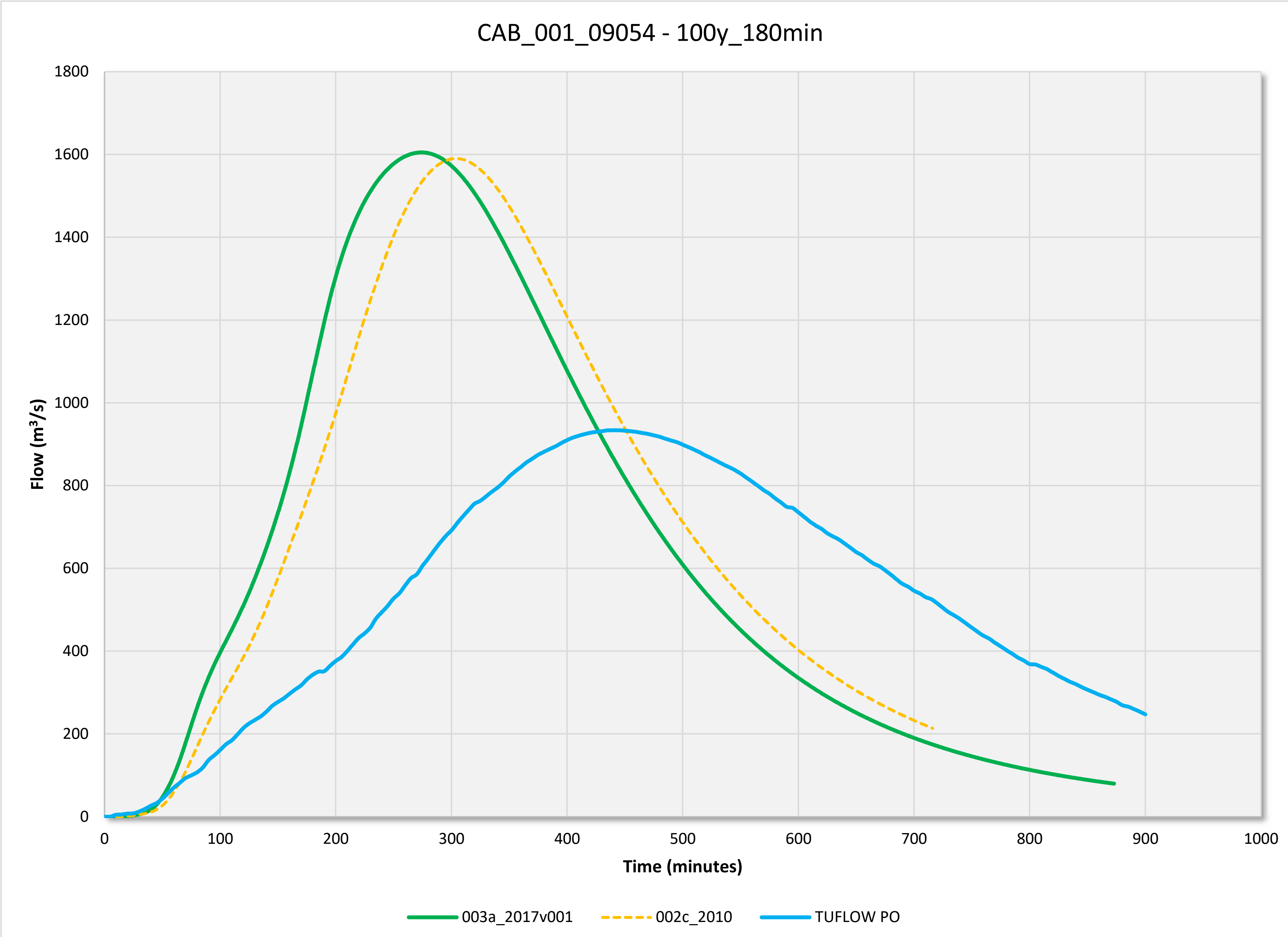

BUR_001_20285 - 20y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO

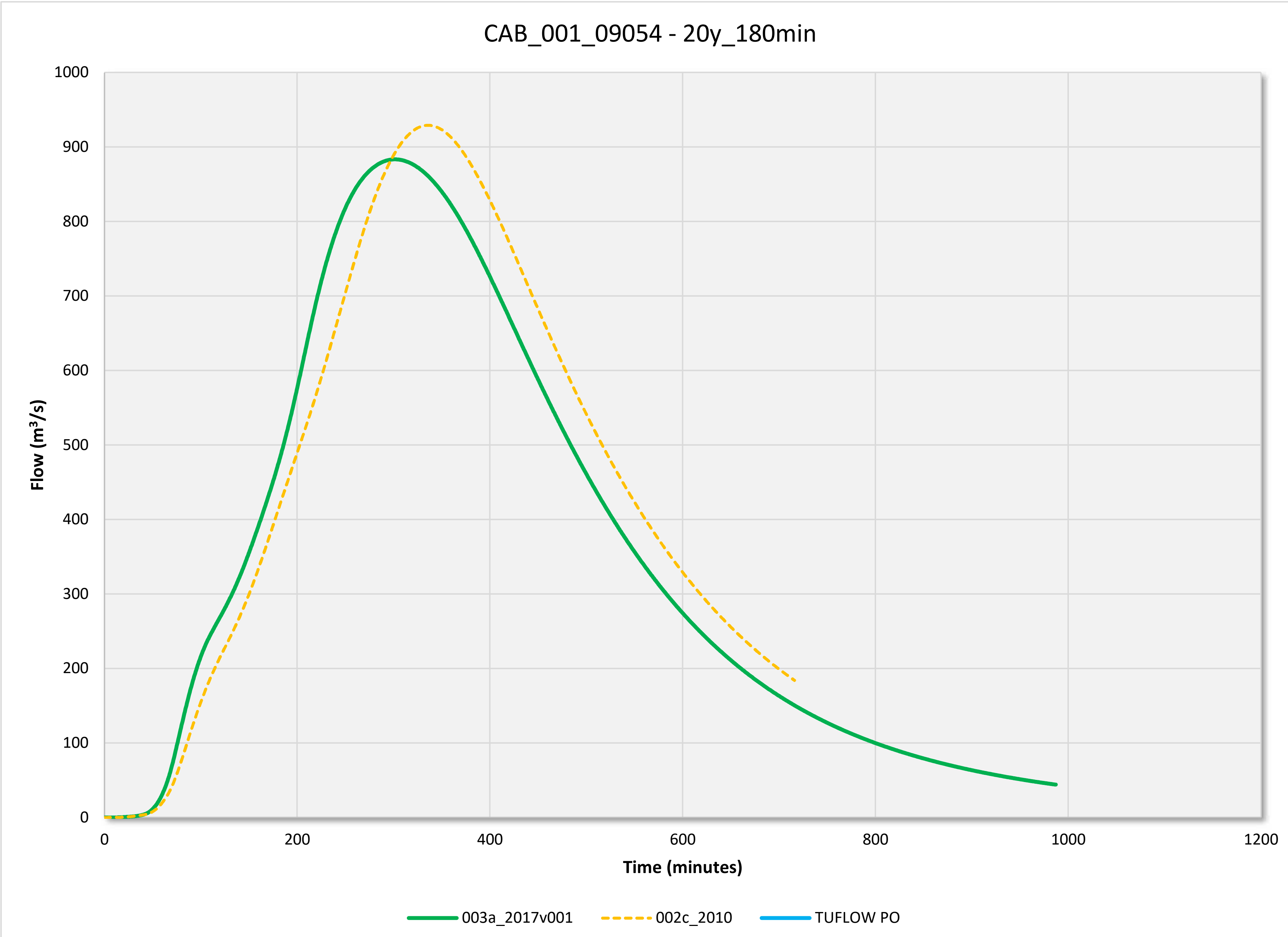


BUR_001_15768 - 100y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
400
450
500
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO

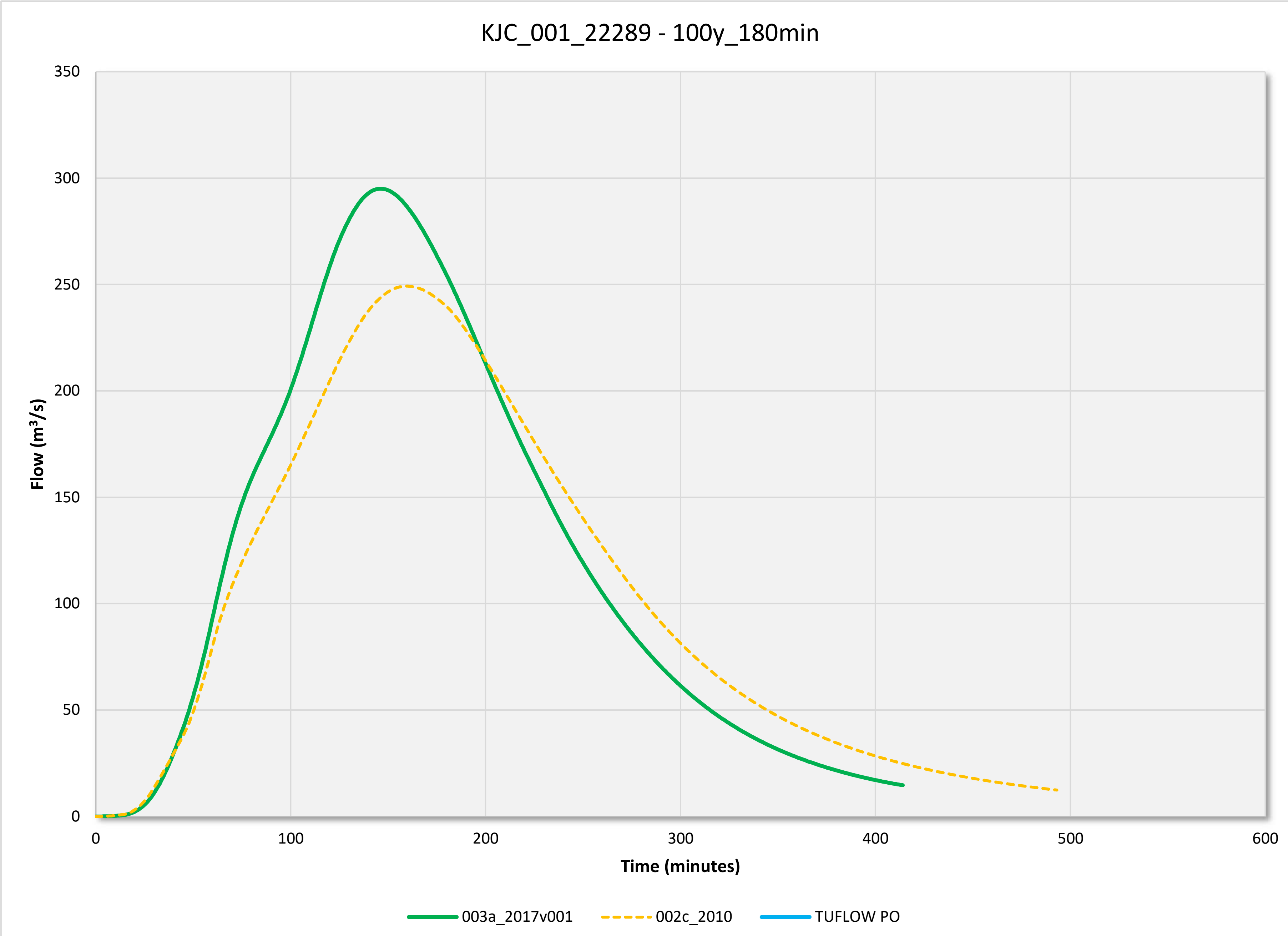


BUR_001_15768 - 20y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600
700
003a_2017v001
002c_2010
TUFLOW PO

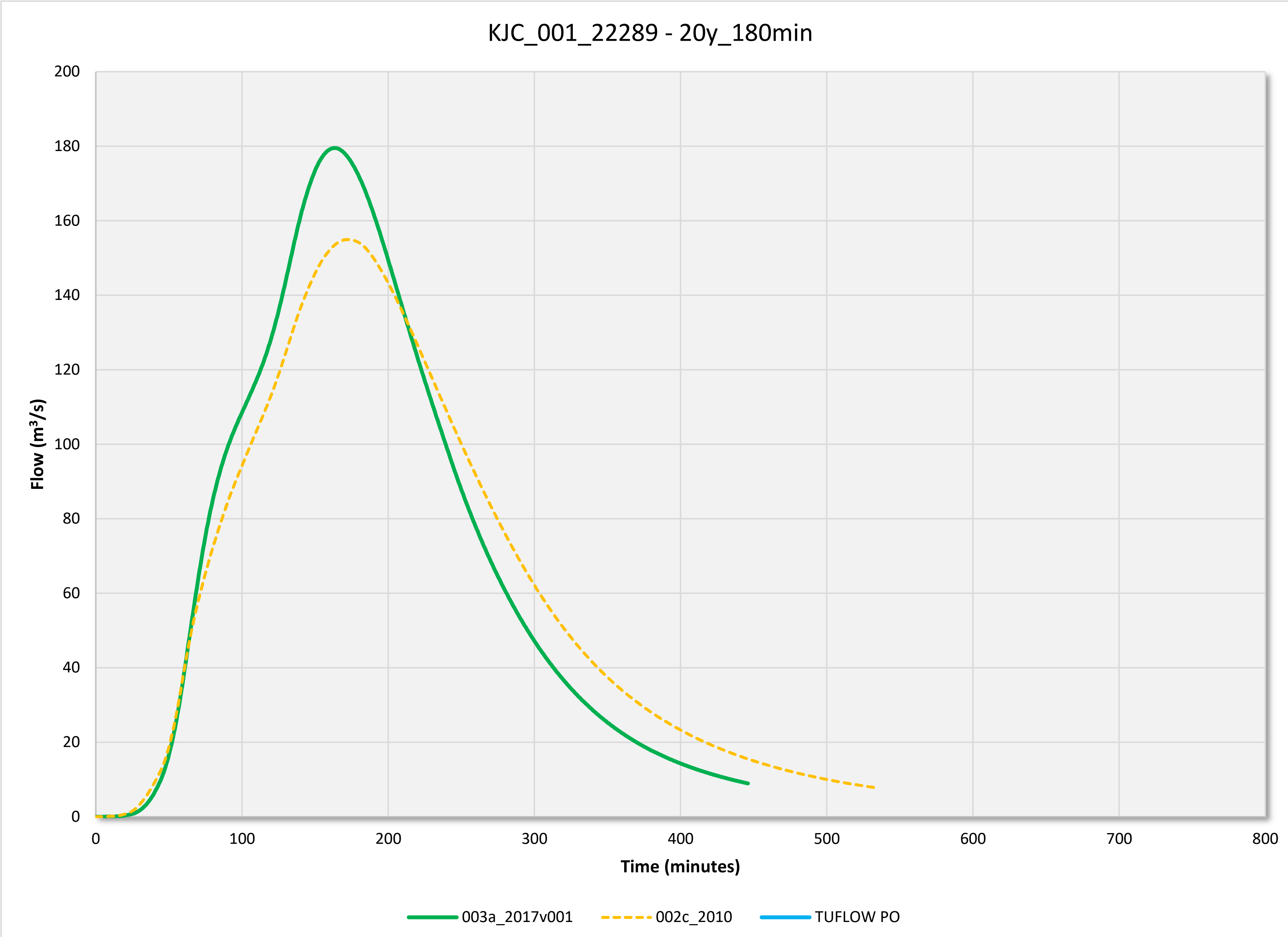

CAB_001_09054 - 100y_180min
Flow (m³/s)
0
200
400
600
800
1000
1200
1400
1600
1800
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
003a_2017v001
002c_2010
TUFLOW PO



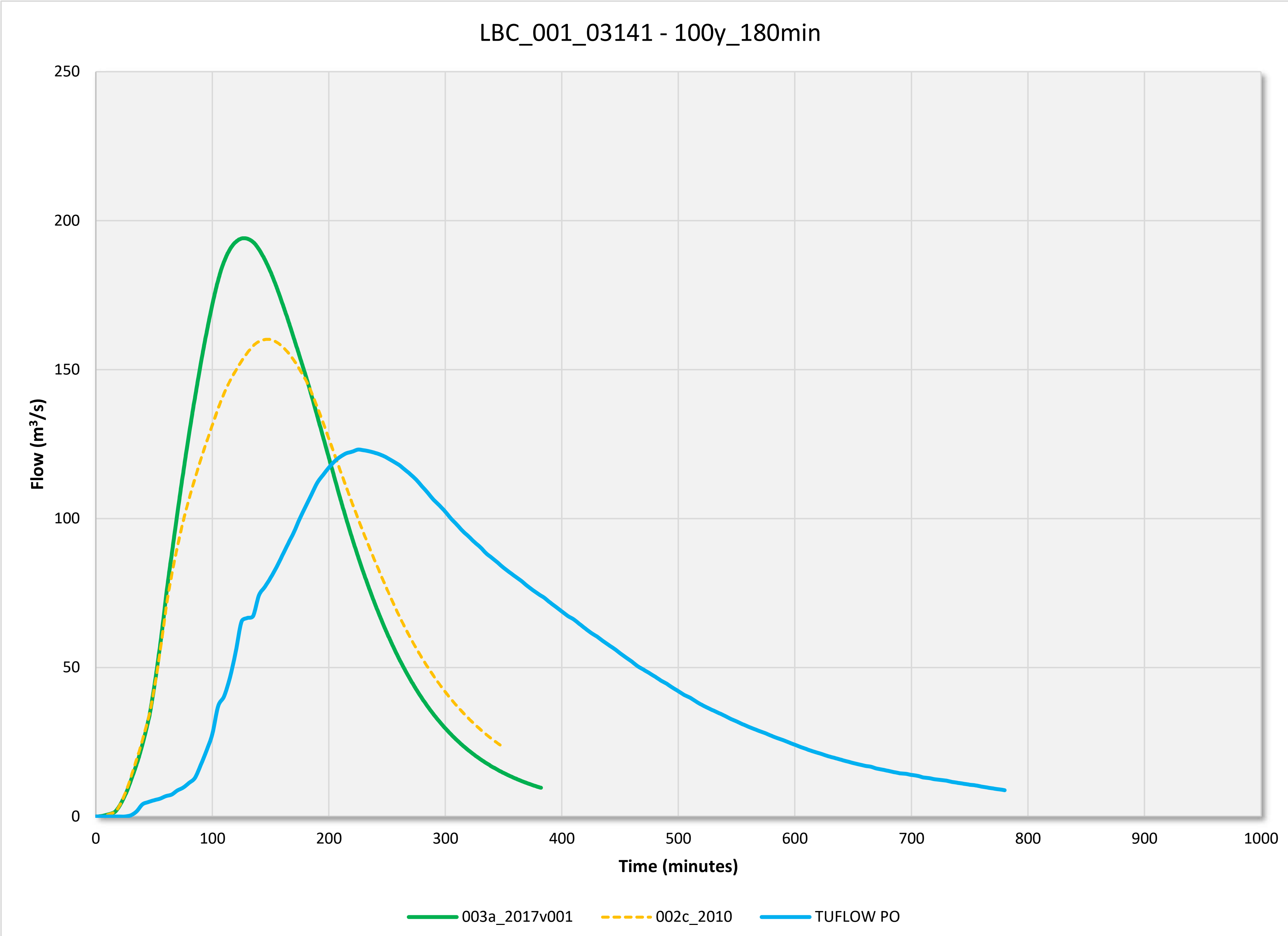
CAB_001_09054 - 20y_180min
Flow (m³/s)
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
0
200
400
600
800
1000
1200
003a_2017v001
002c_2010
TUFLOW PO



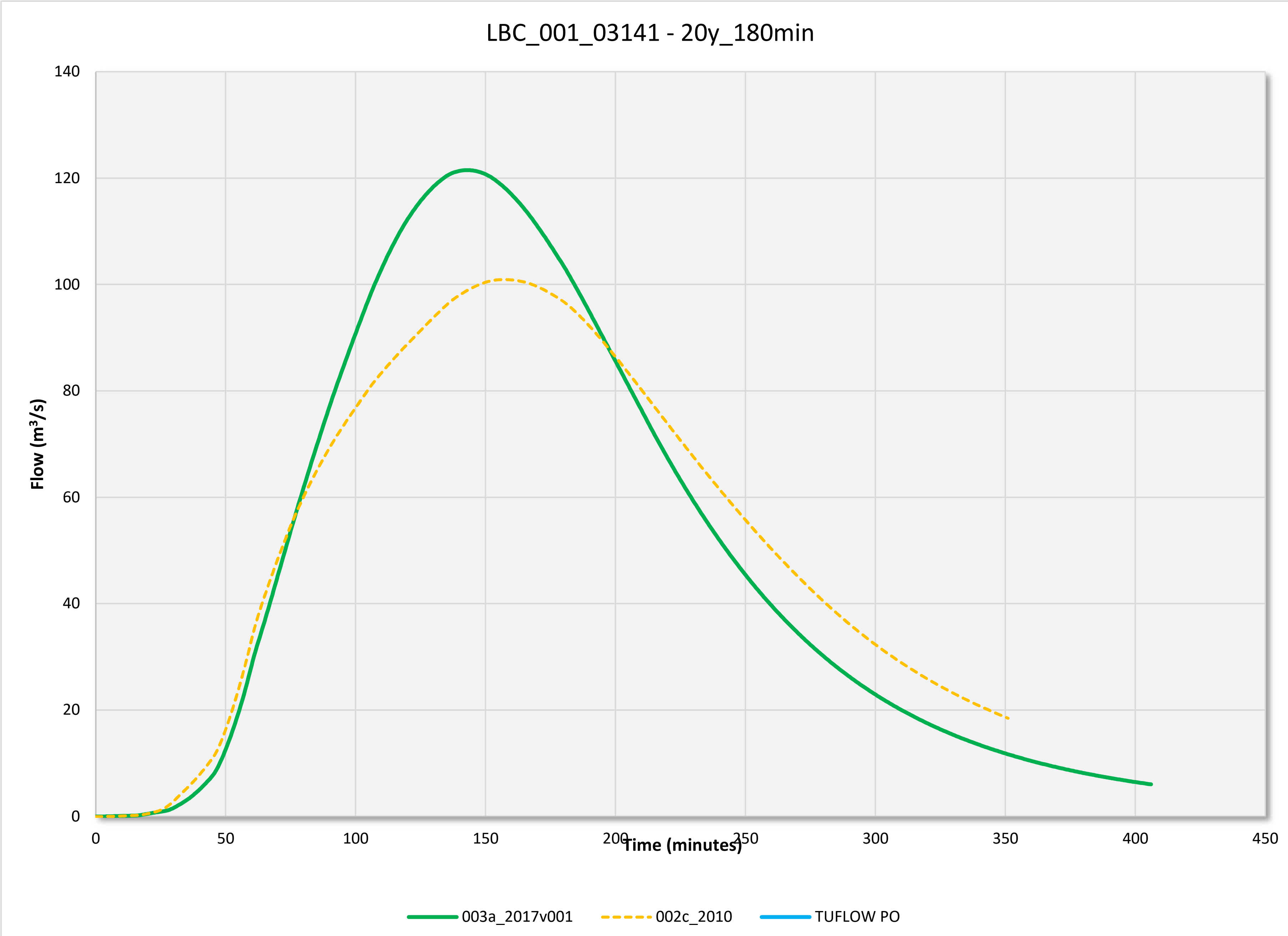
KJC_001_22289 - 100y_180min
Flow (m³/s)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



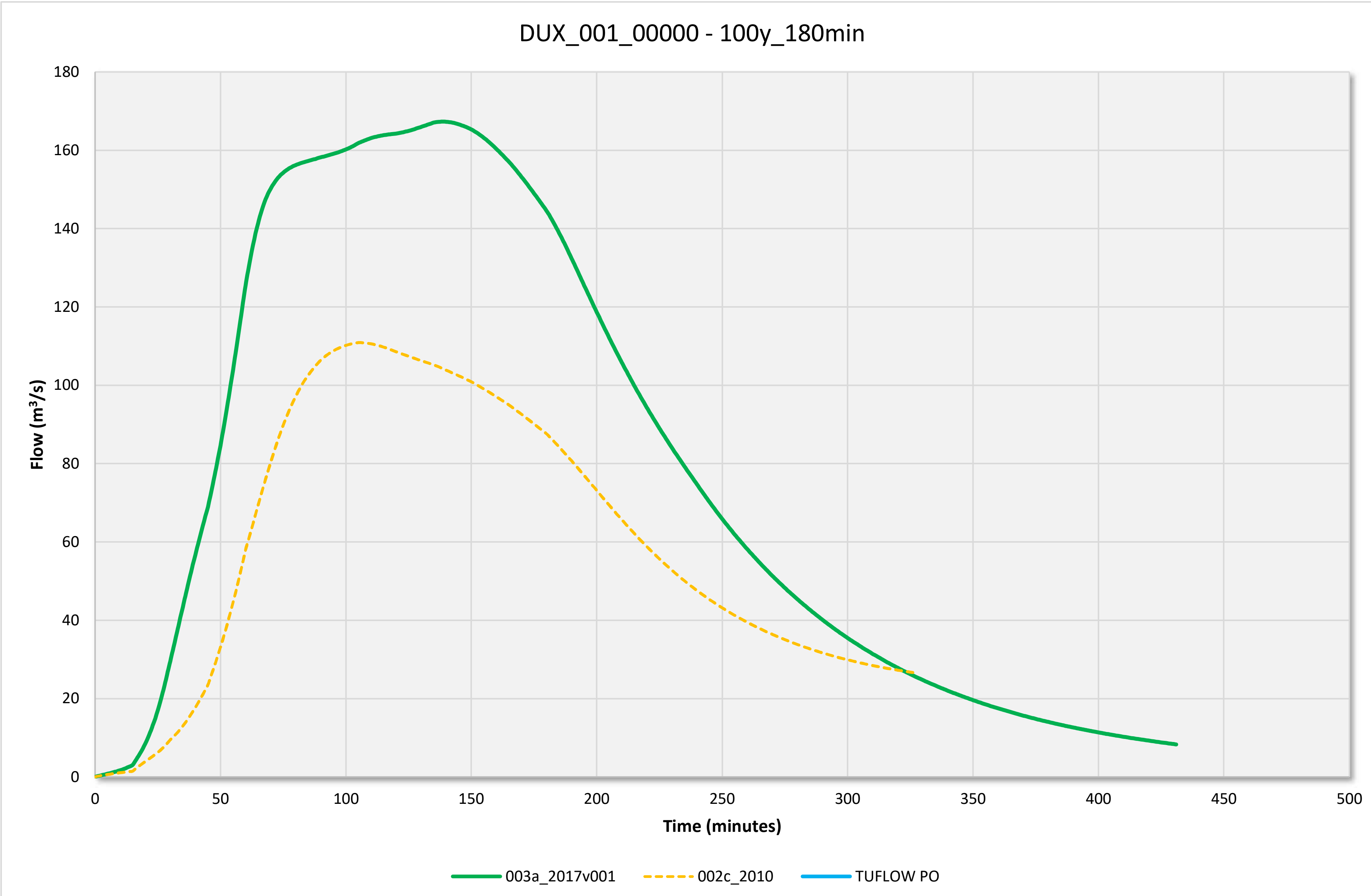
KJC_001_22289 - 20y_180min
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



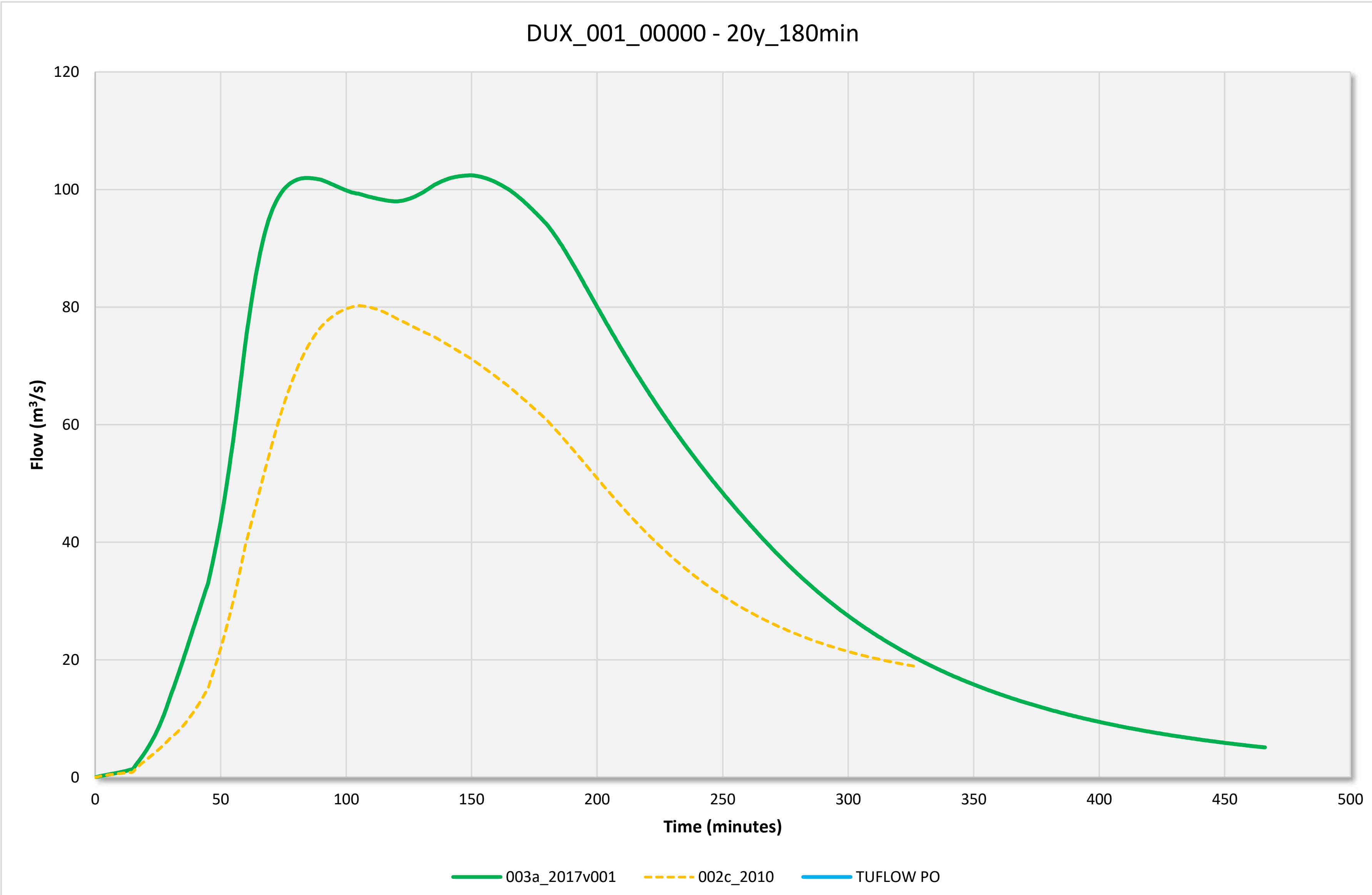
LBC_001_03141 - 100y_180min
250
200
150
100
50
0
Flow (m³/s)
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

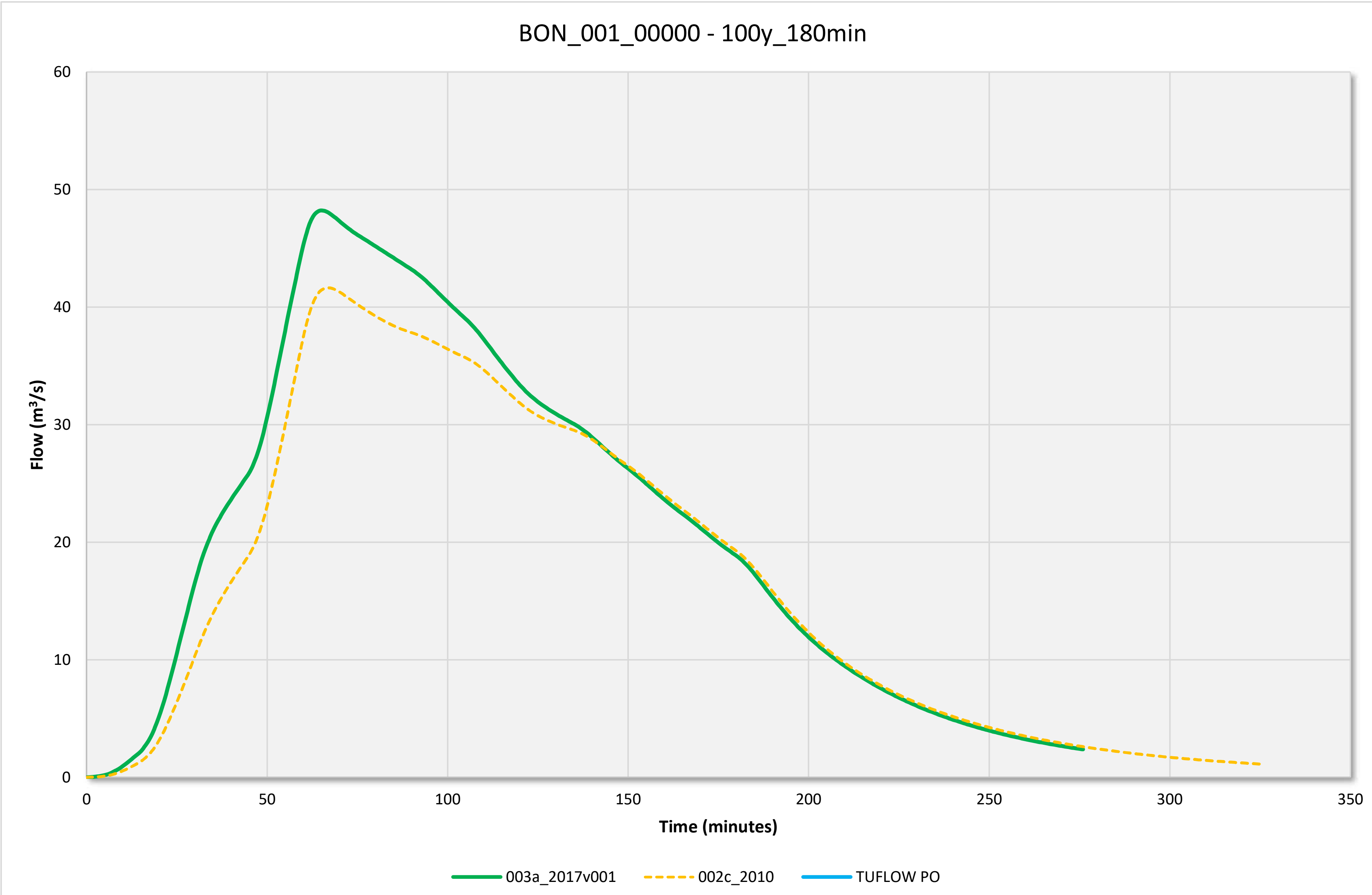


LBC_001_03141 - 20y_180min
Flow (m³/s)
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

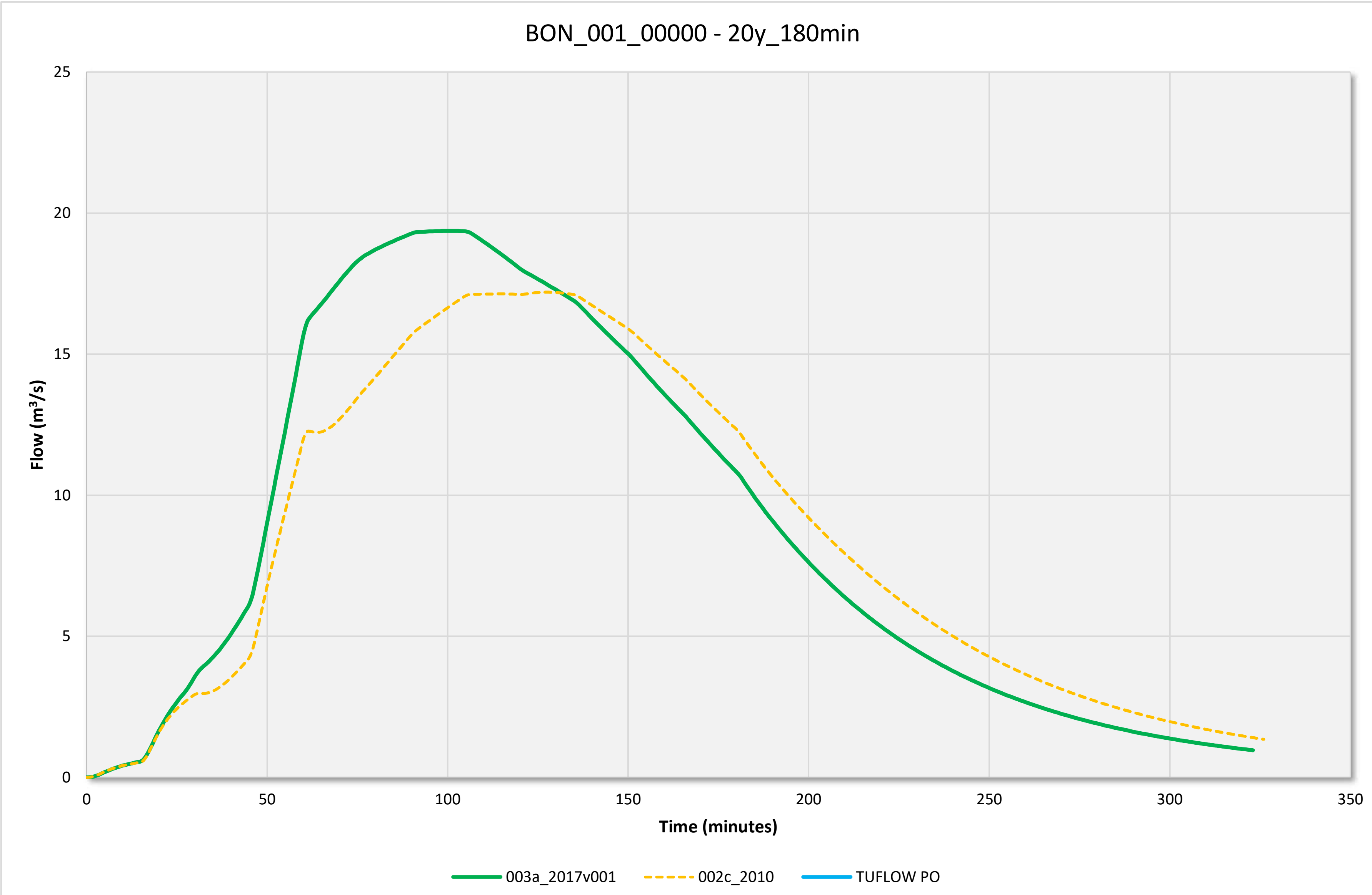


DUX_001_00000 - 100y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
250
300
350
400
450
500
003a_2017v001
002c_2010
TUFLOW PO

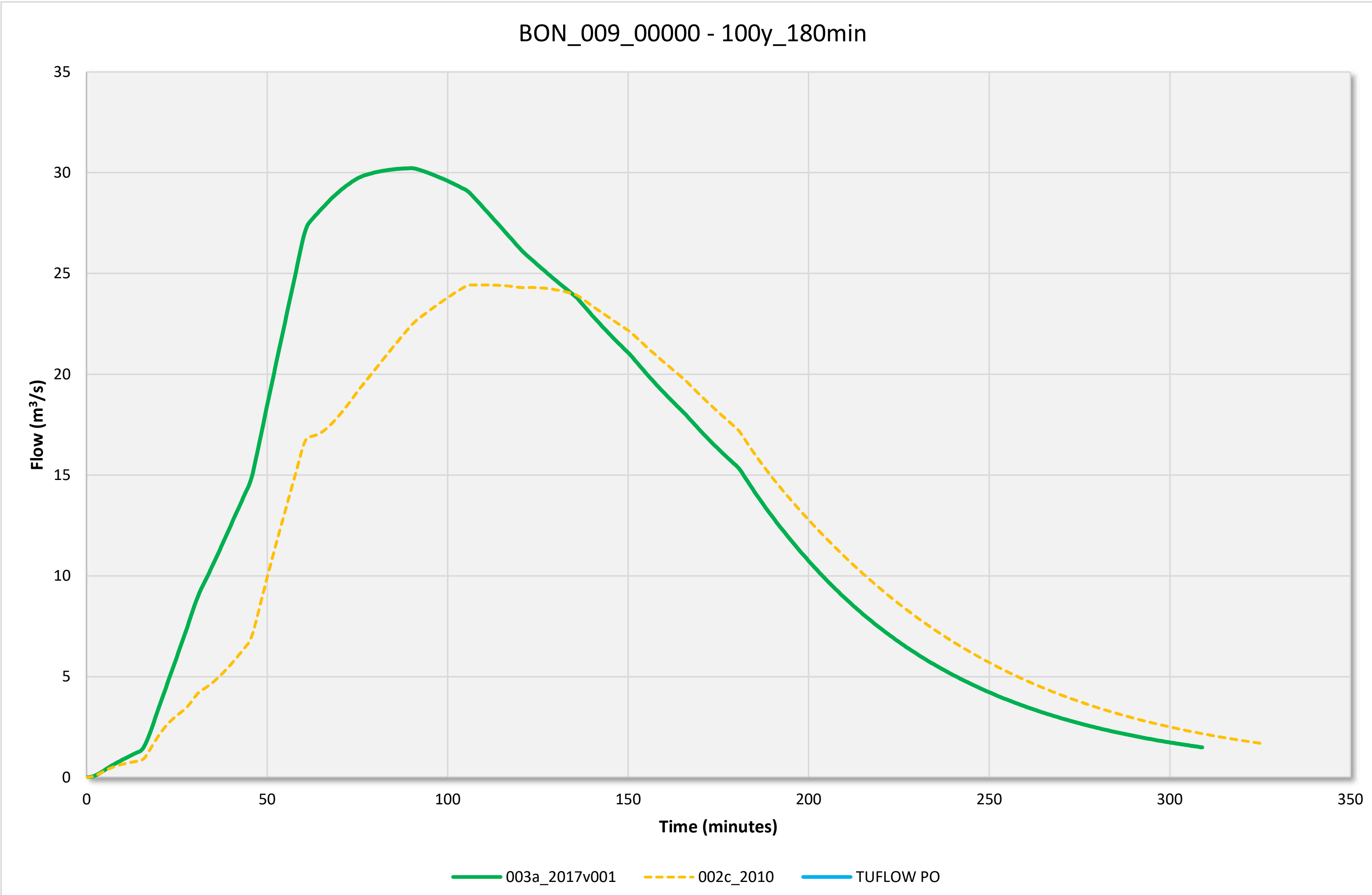

DUX_001_00000 - 20y_180min
Flow (m³/s)
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



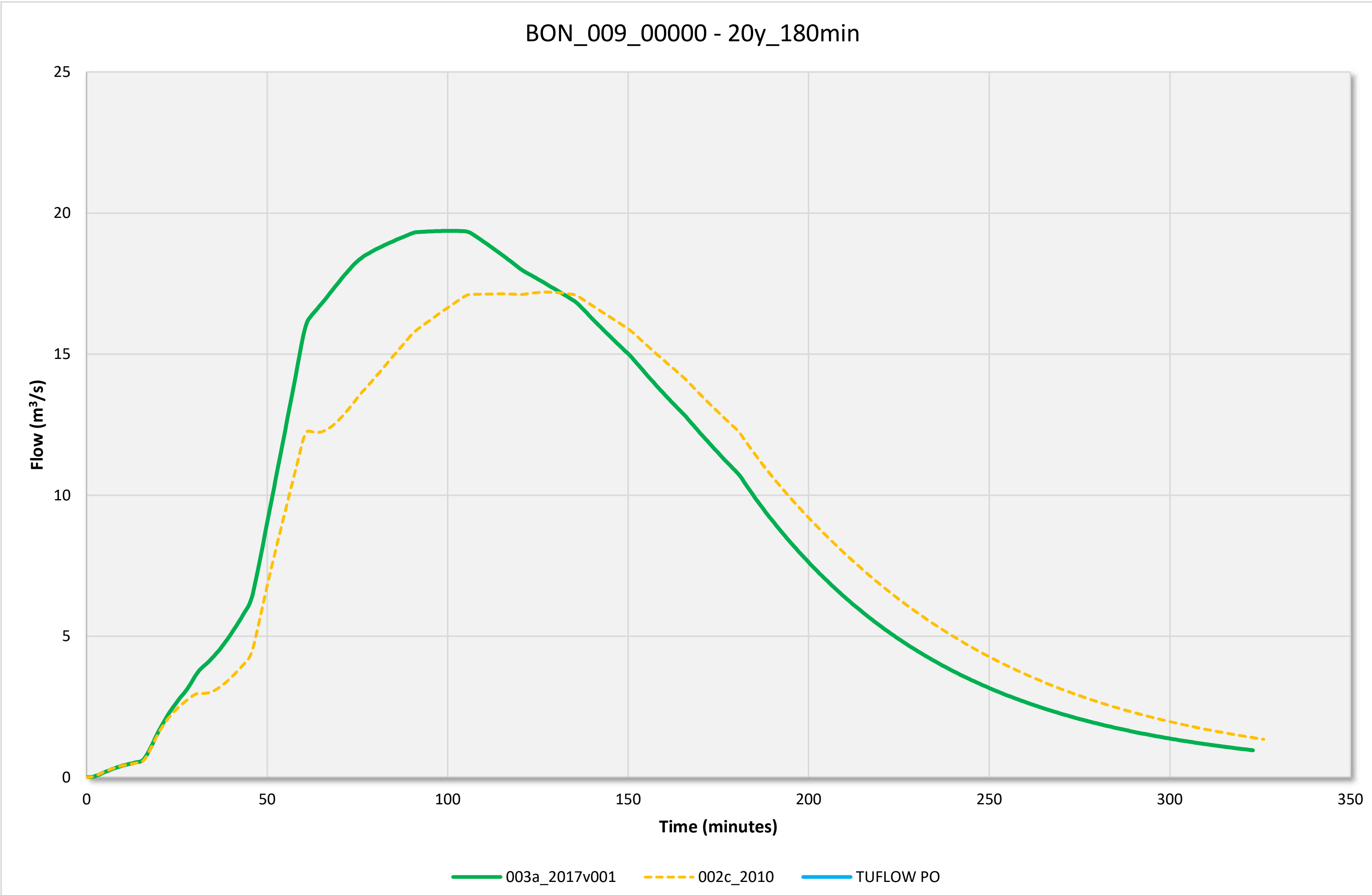
BON_001_00000 - 100y_180min
Flow (m³/s)
0
10
20
30
40
50
60
Time (minutes)
0
50
100
150
200
250
300
350
003a_2017v001
002c_2010
TUFLOW PO

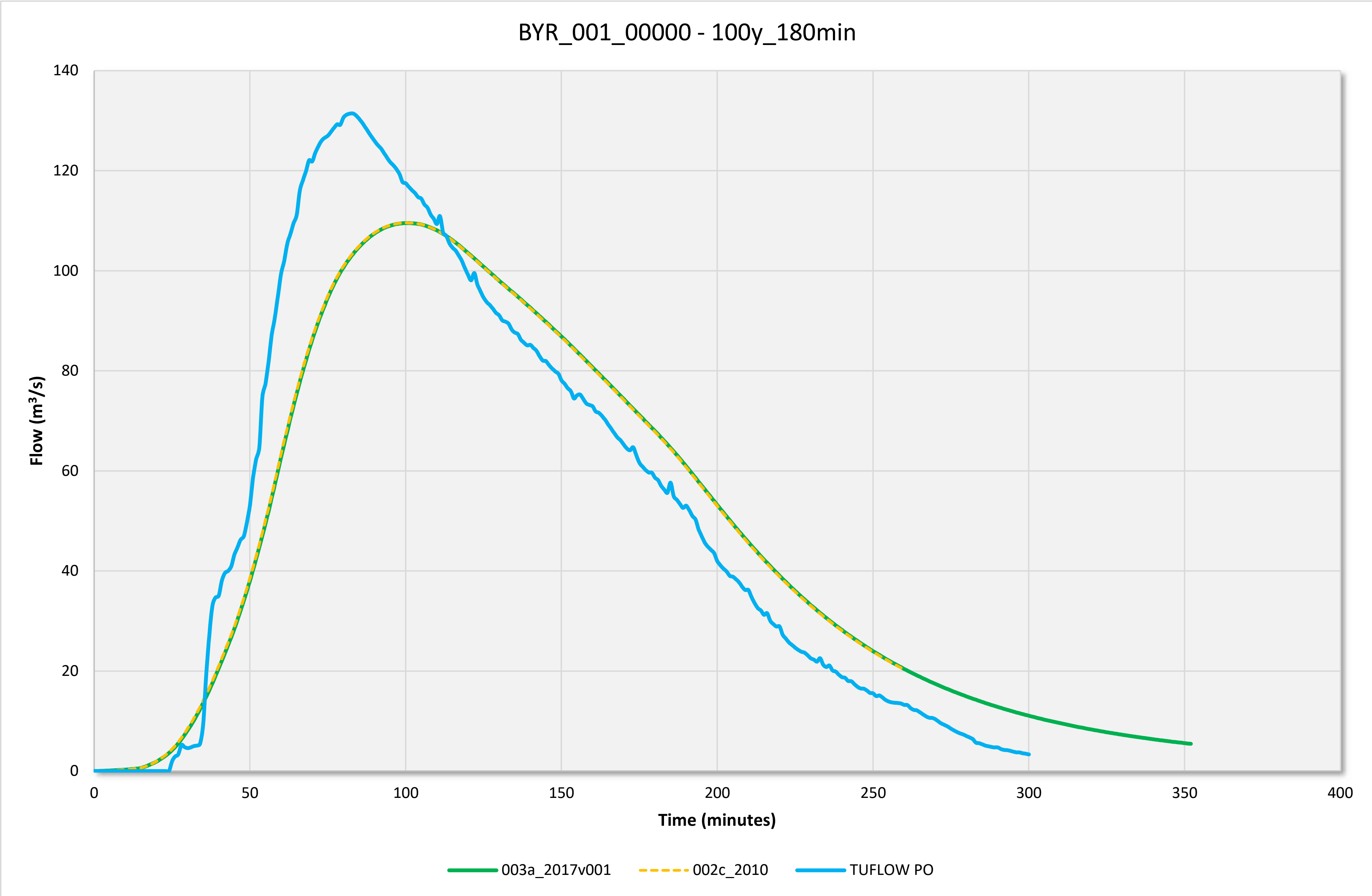


BON_001_00000 - 20y_180min
Flow (m3/s)
25
20
15
10
5
0
0
50
100
150
200
250
300
350
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

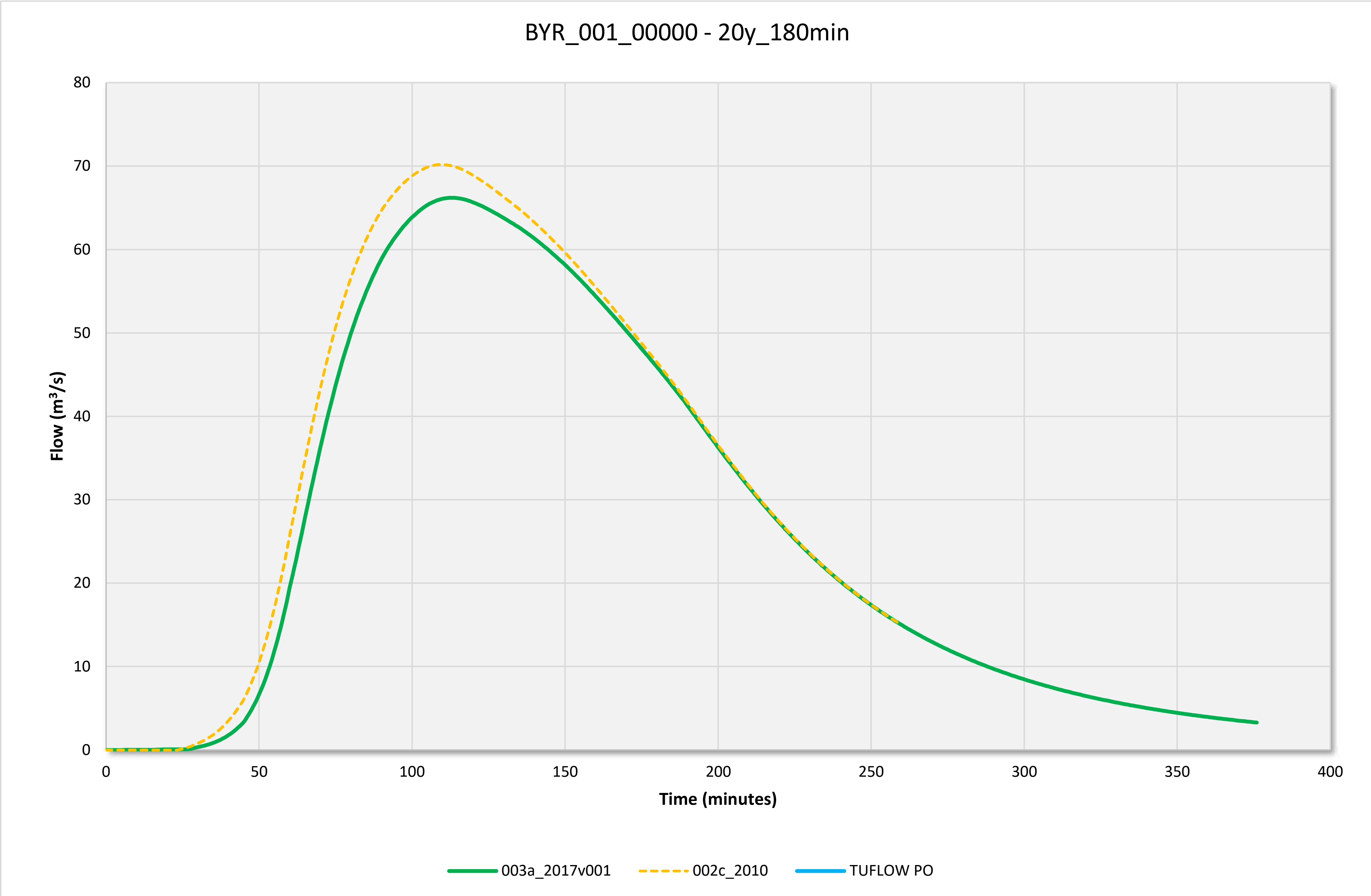


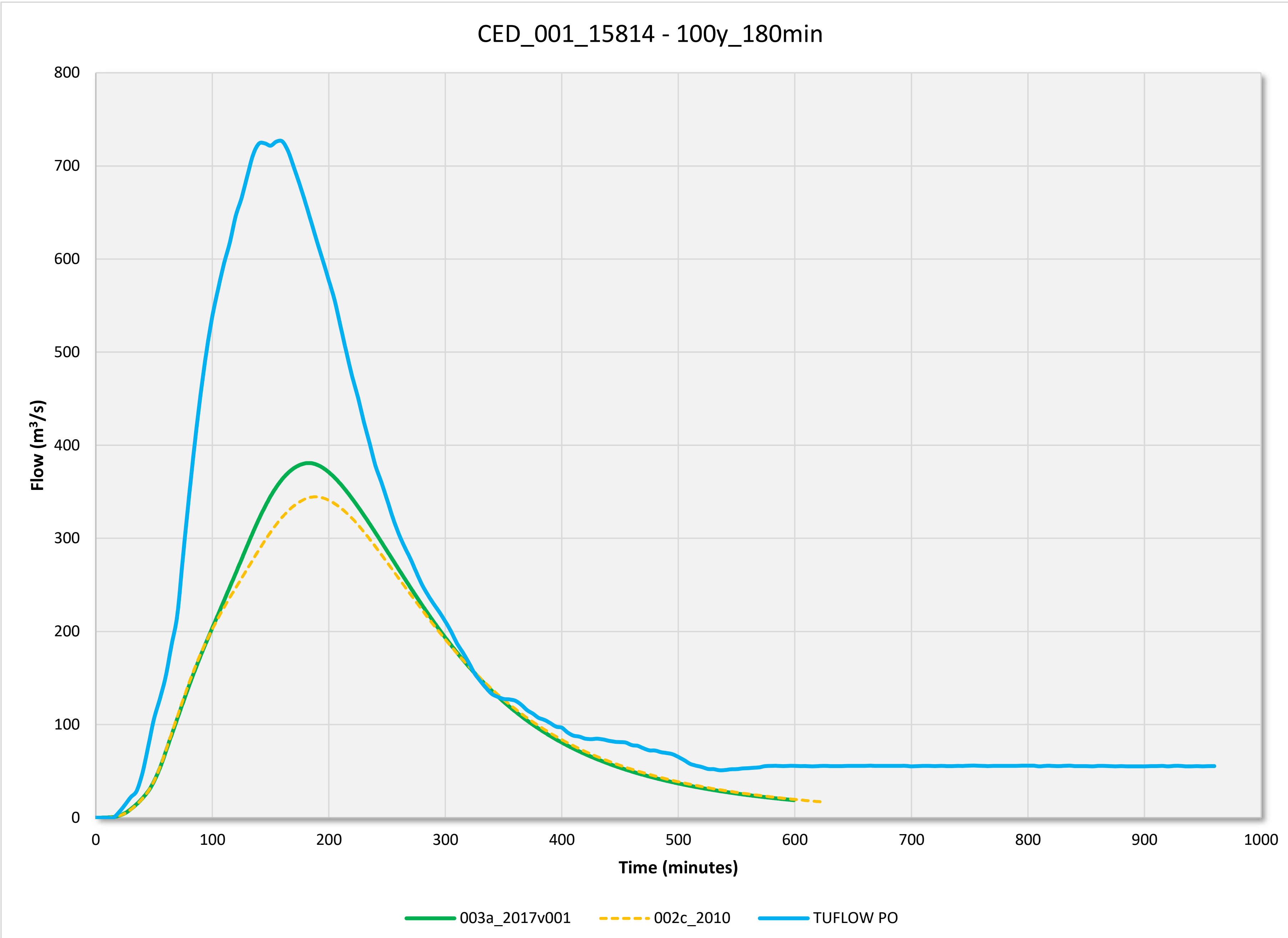
BON_009_00000 - 100y_180min
Flow (m³/s)
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


BON_009_00000 - 20y_180min
Flow (m³/s)
Time (minutes)
0
5
10
15
20
25
0
50
100
150
200
250
300
350
003a_2017v001
002c_2010
TUFLOW PO

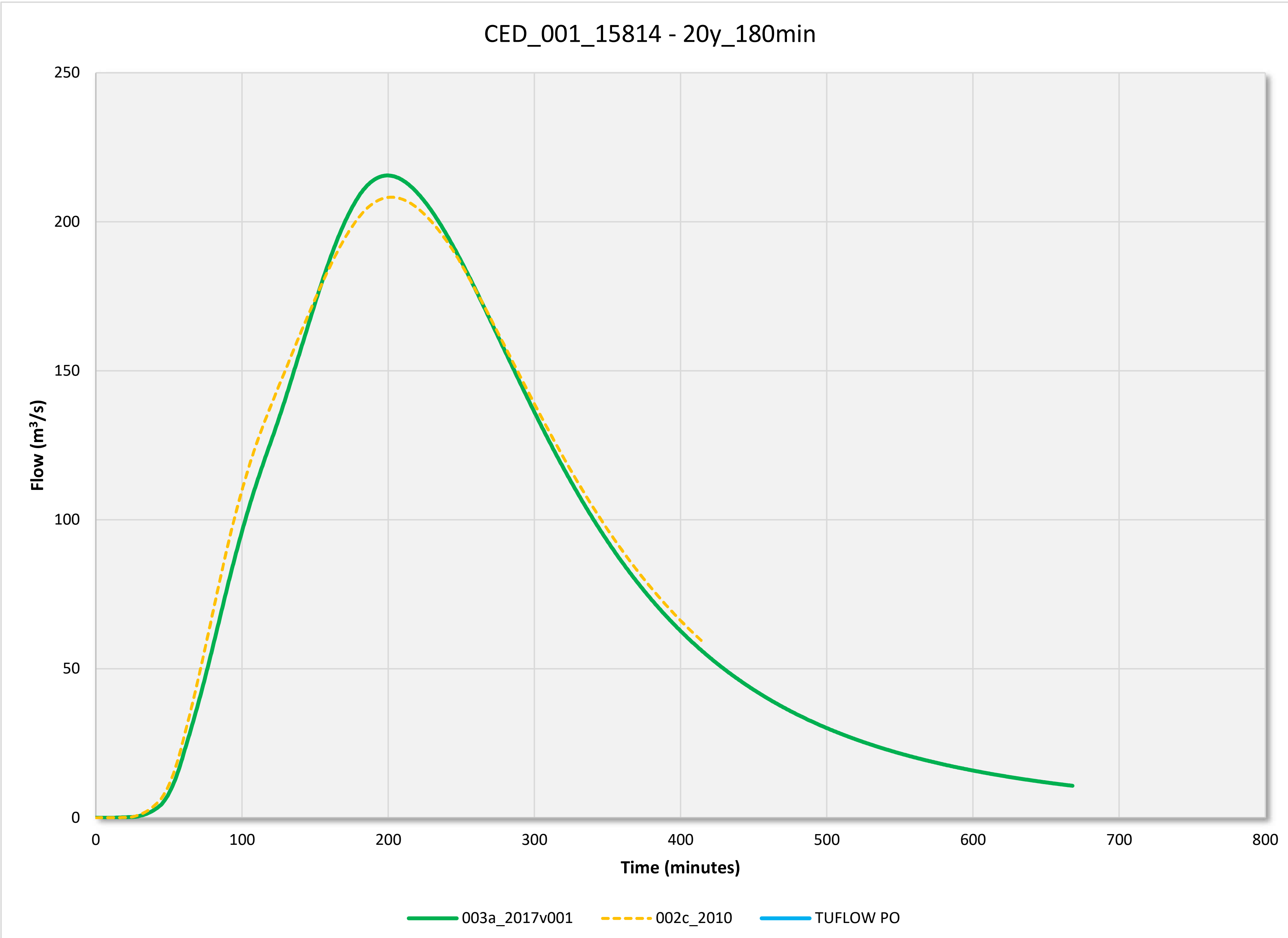


BYR_001_00000 - 100y_180min
Flow (m³/s)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

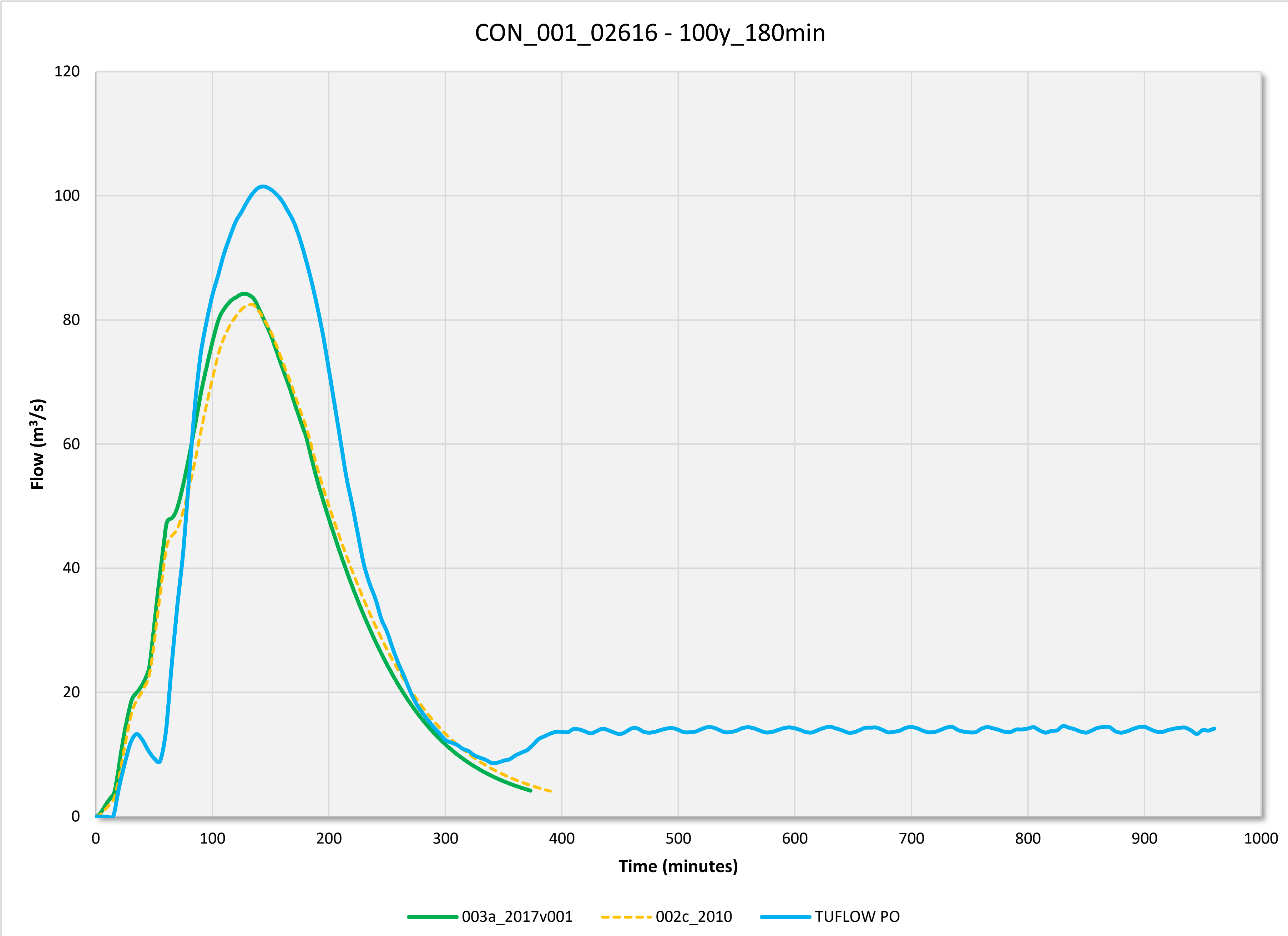

BYR_001_00000 - 20y_180min
Flow (m³/s)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

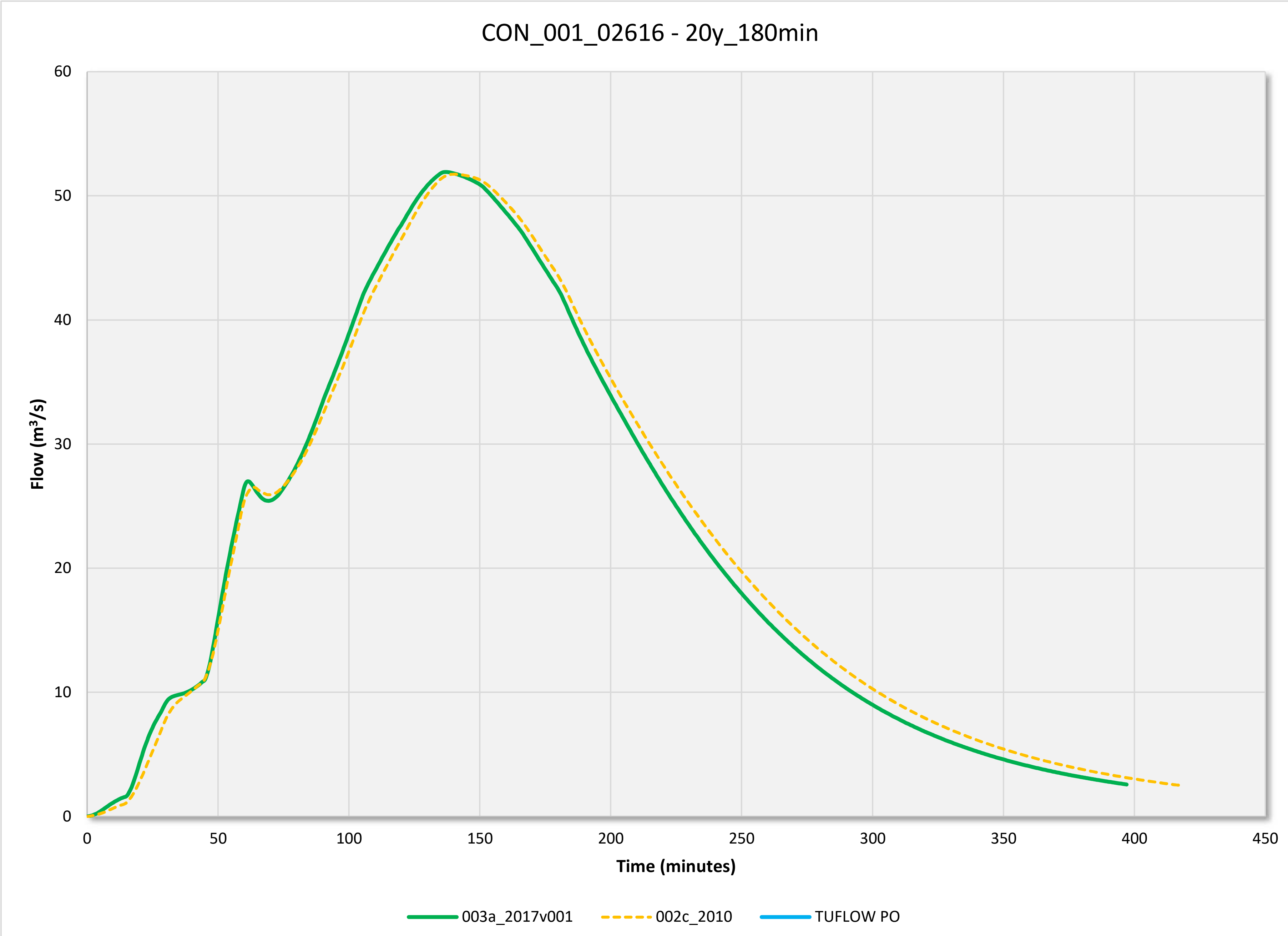


CED_001_15814 - 100y_180min
Flow (m³/s)
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
003a_2017v001
002c_2010
TUFLOW PO

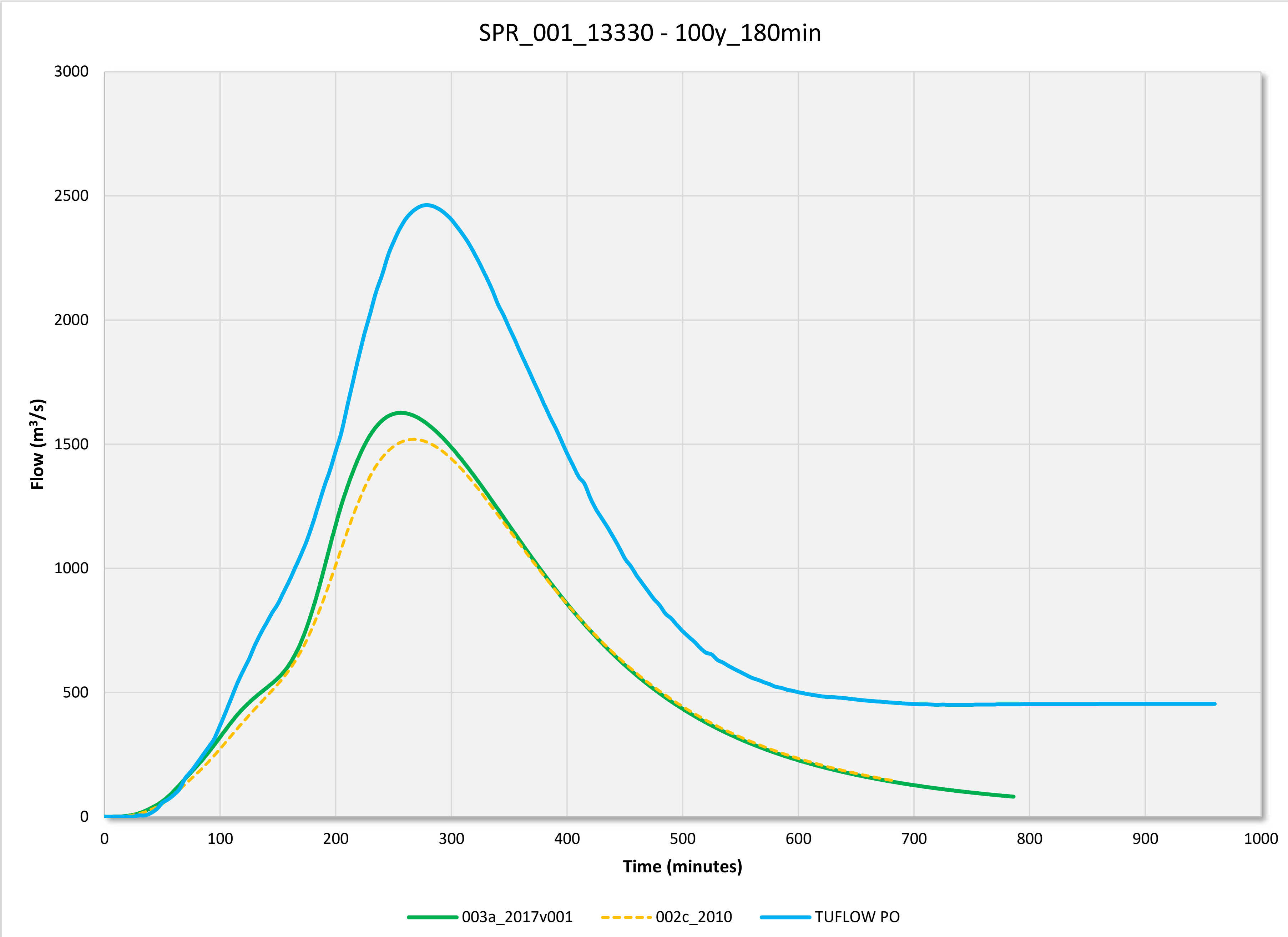


CED_001_15814 - 20y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

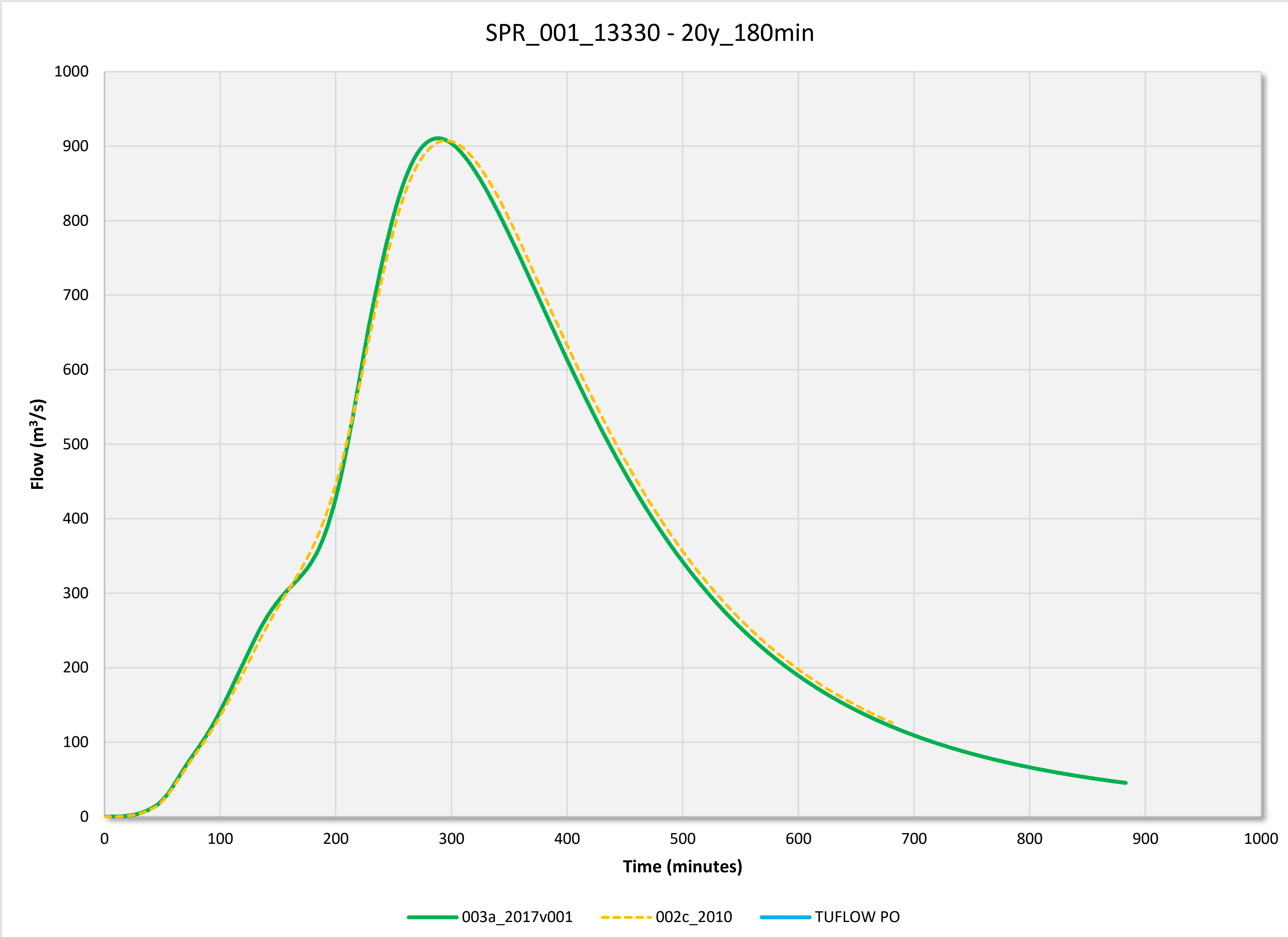

CON_001_02616 - 100y_180min
Flow (m³/s)
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

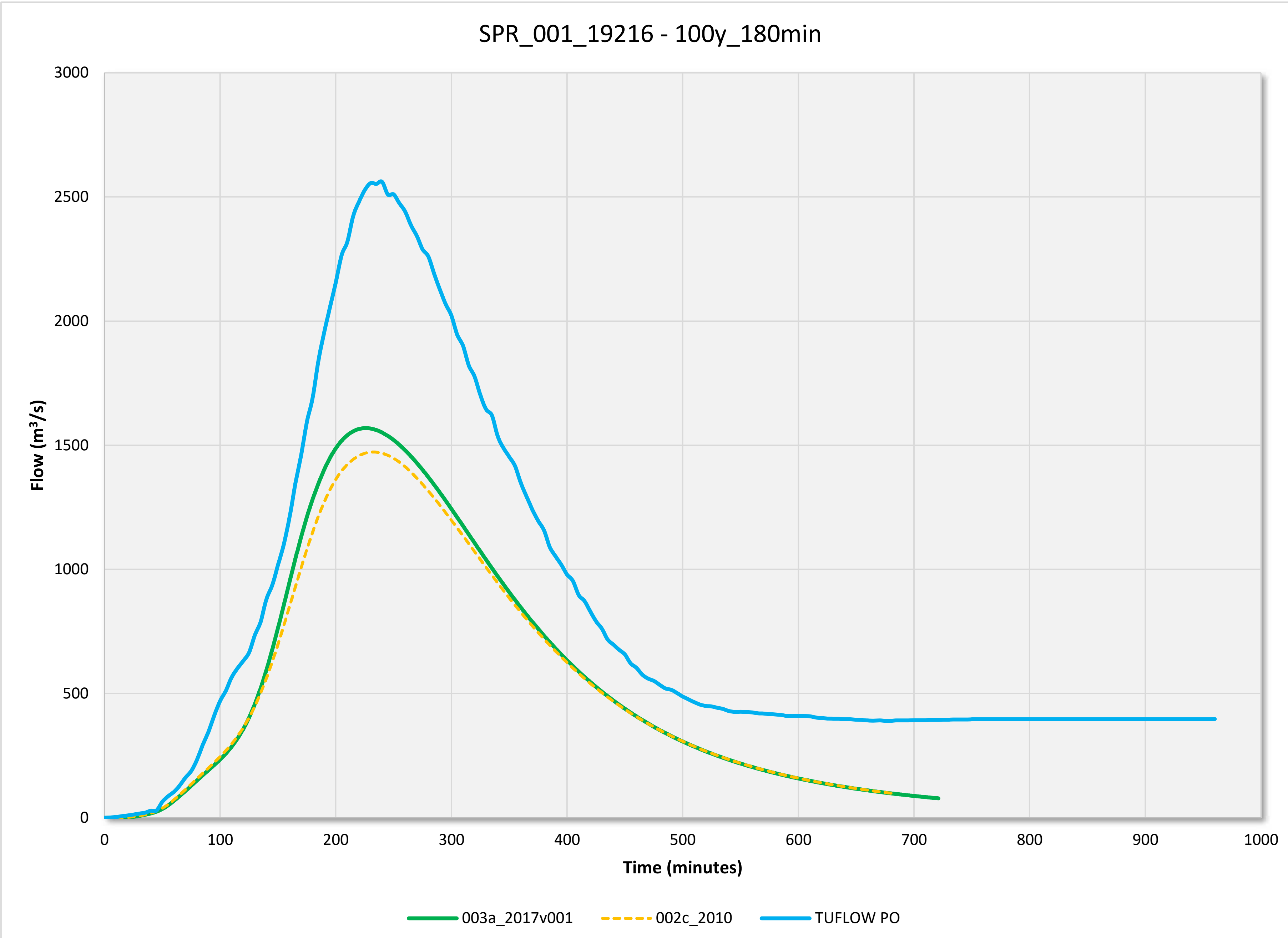


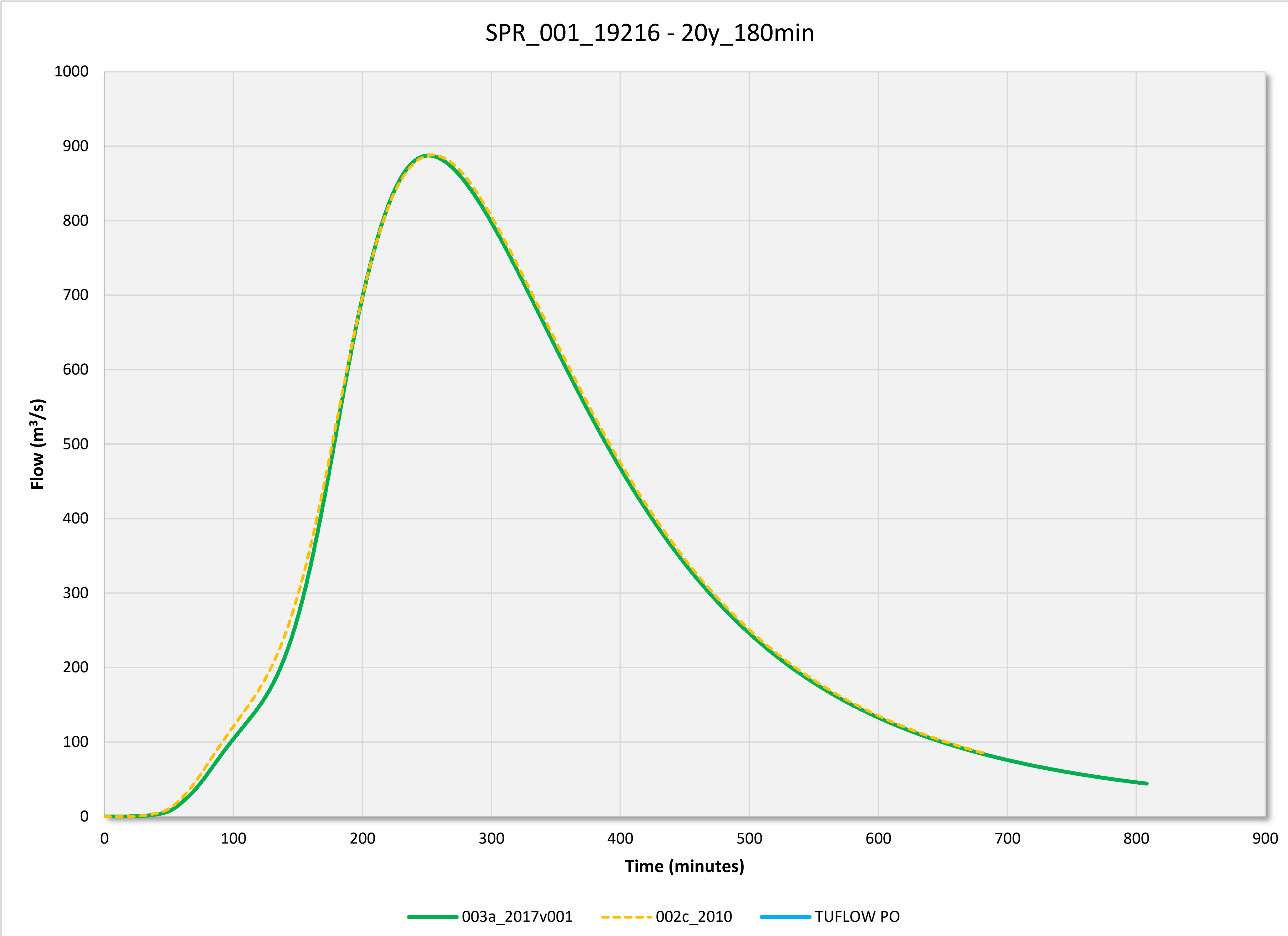
CON_001_02616 - 20y_180min
Flow (m³/s)
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

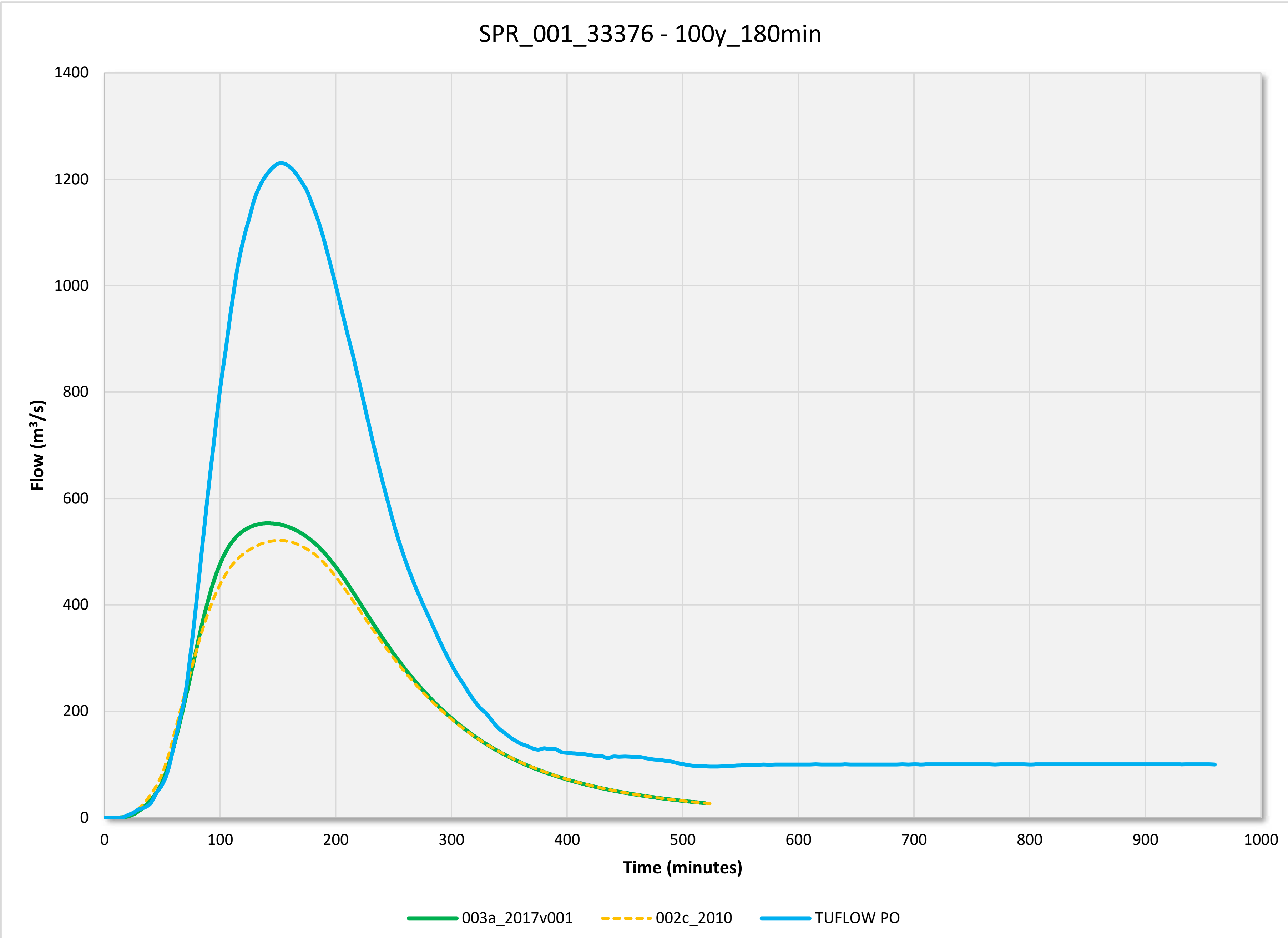


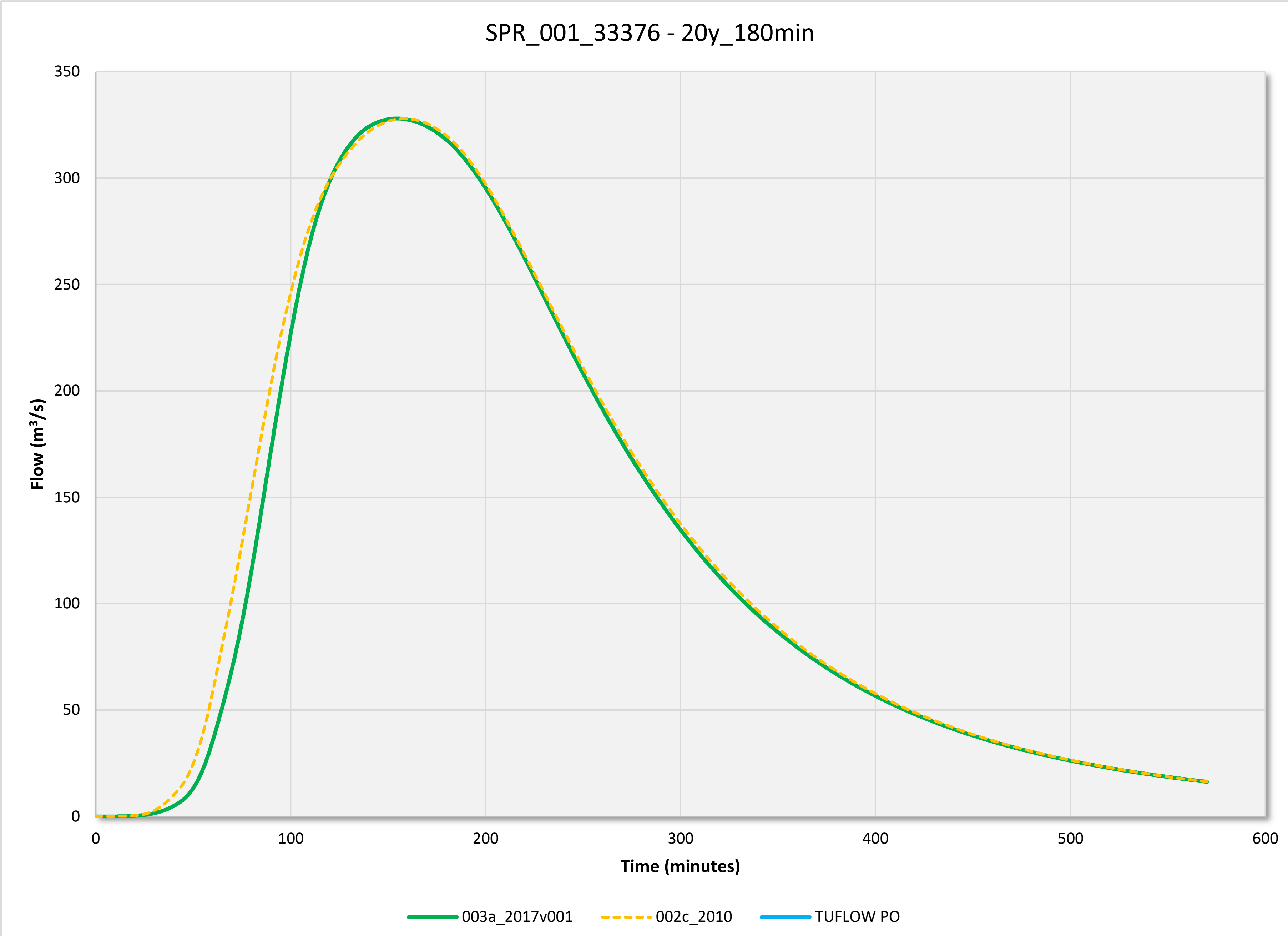
SPR_001_13330 - 100y_180min
Flow (m³/s)
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


SPR_001_13330 - 20y_180min
Flow (m³/s)
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

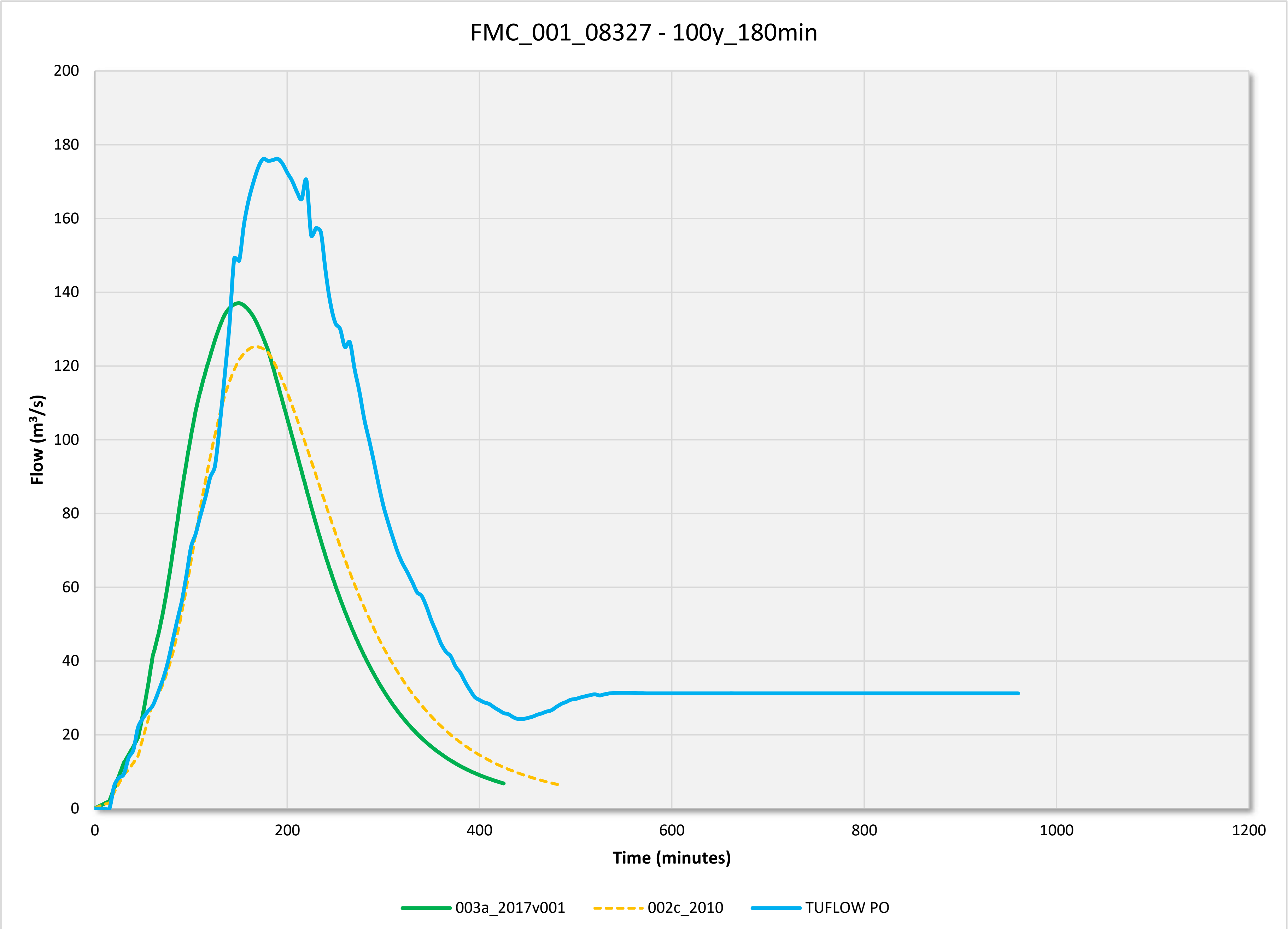

SPR_001_19216 - 100y_180min
3000
2500
2000
1500
1000
500
0
Flow (m³/s)
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


SPR_001_19216 - 20y_180min
Flow (m³/s)
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO

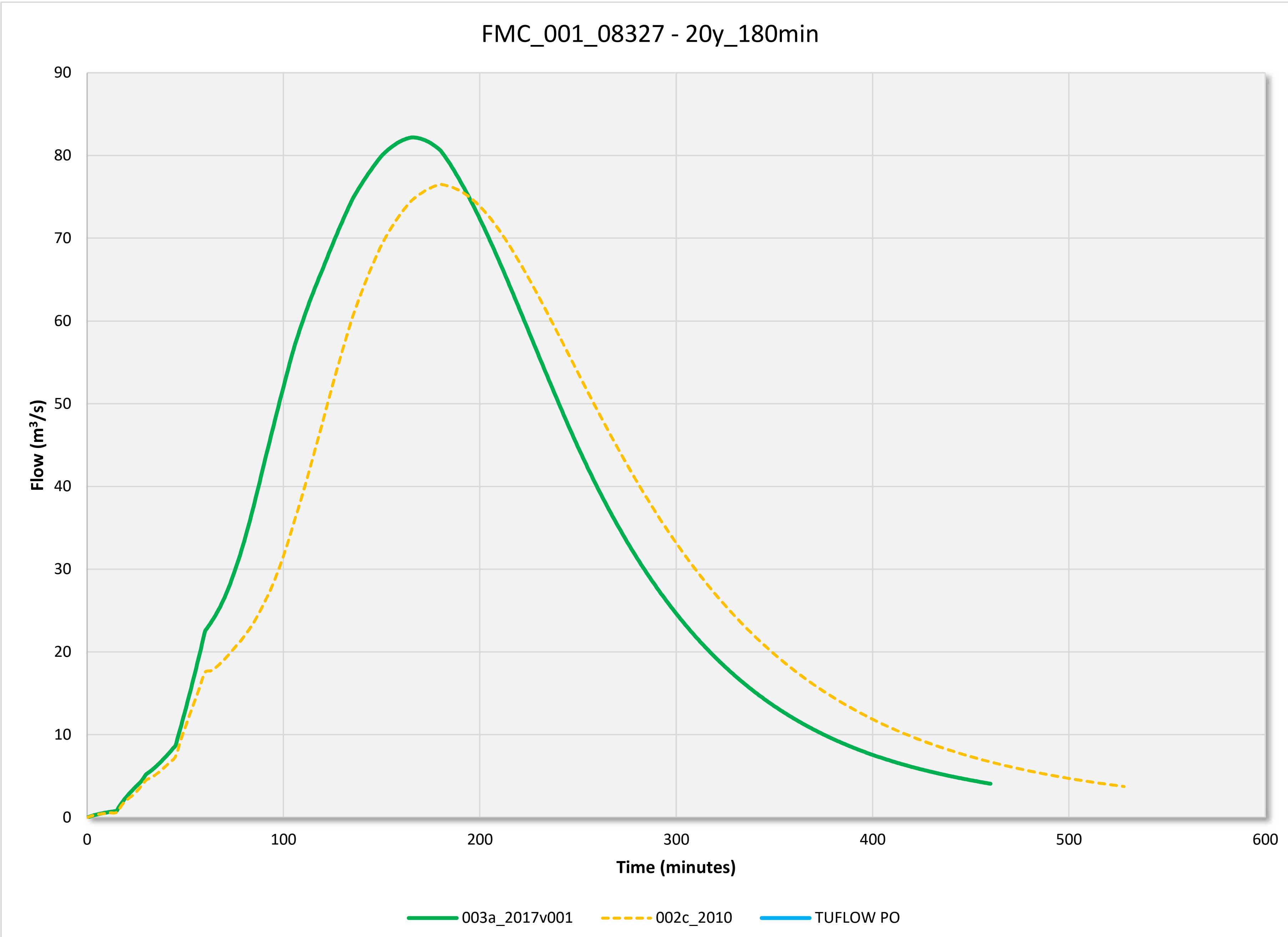

SPR_001_33376 - 100y_180min
Flow (m³/s)
Time (minutes)
0
200
400
600
800
1000
1200
1400
0
100
200
300
400
500
600
700
800
900
1000
003a_2017v001
002c_2010
TUFLOW PO

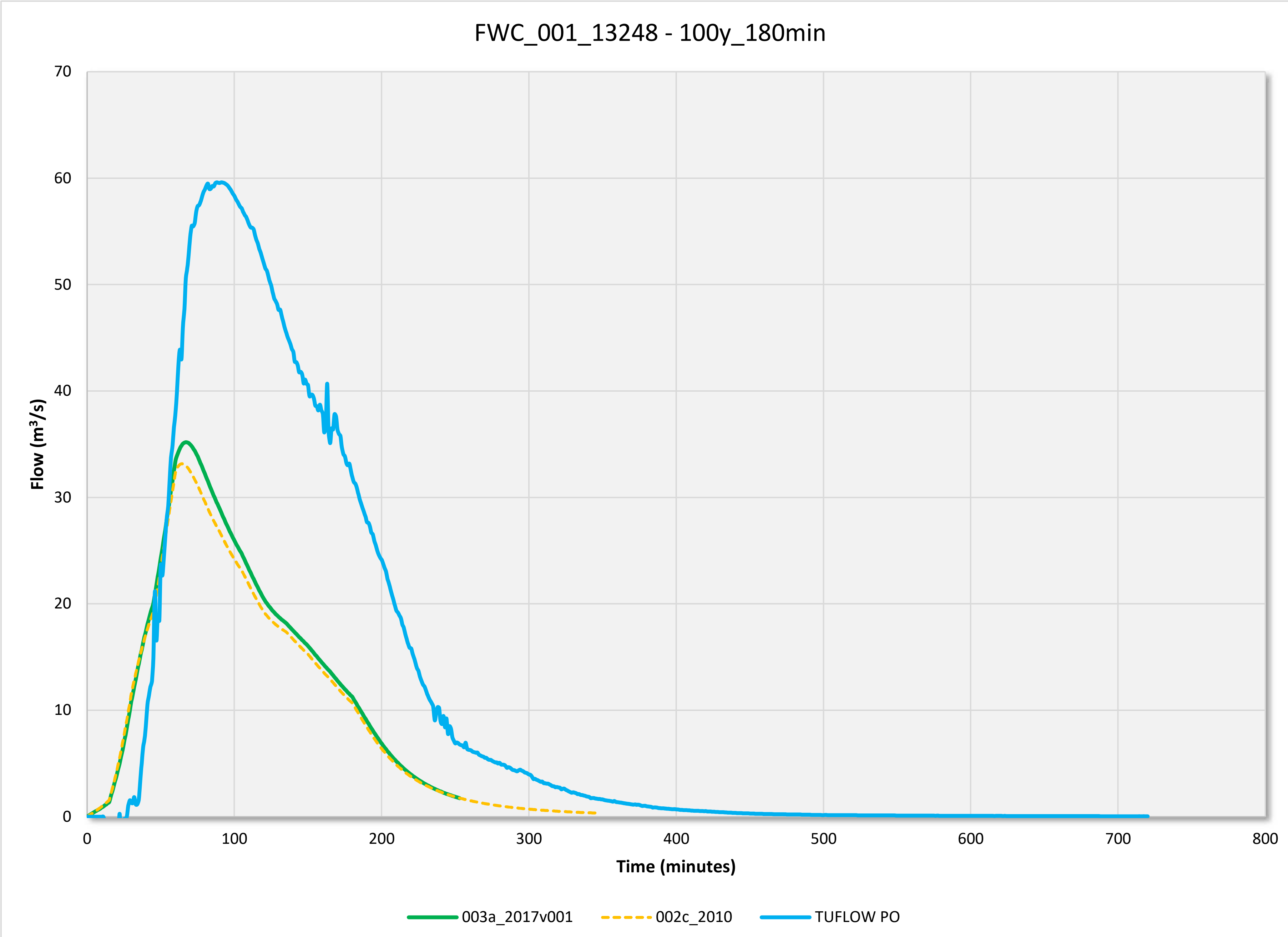


SPR_001_33376 - 20y_180min
Flow (m³/s)
0
50
100
150
200
250
300
350
Time (minutes)
0
100
200
300
400
500
600
003a_2017v001
002c_2010
TUFLOW PO

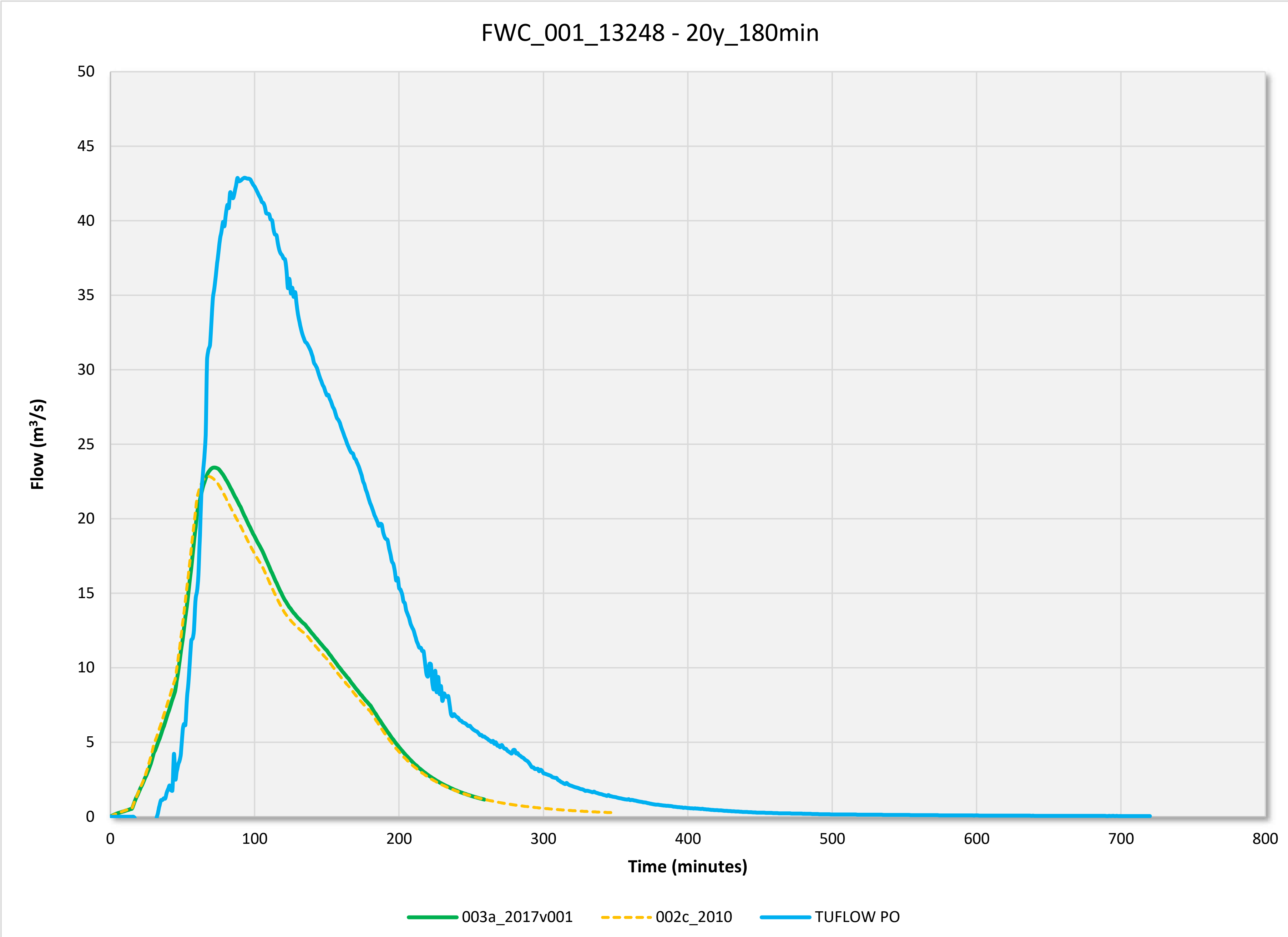


FMC_001_08327 - 100y_180min
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

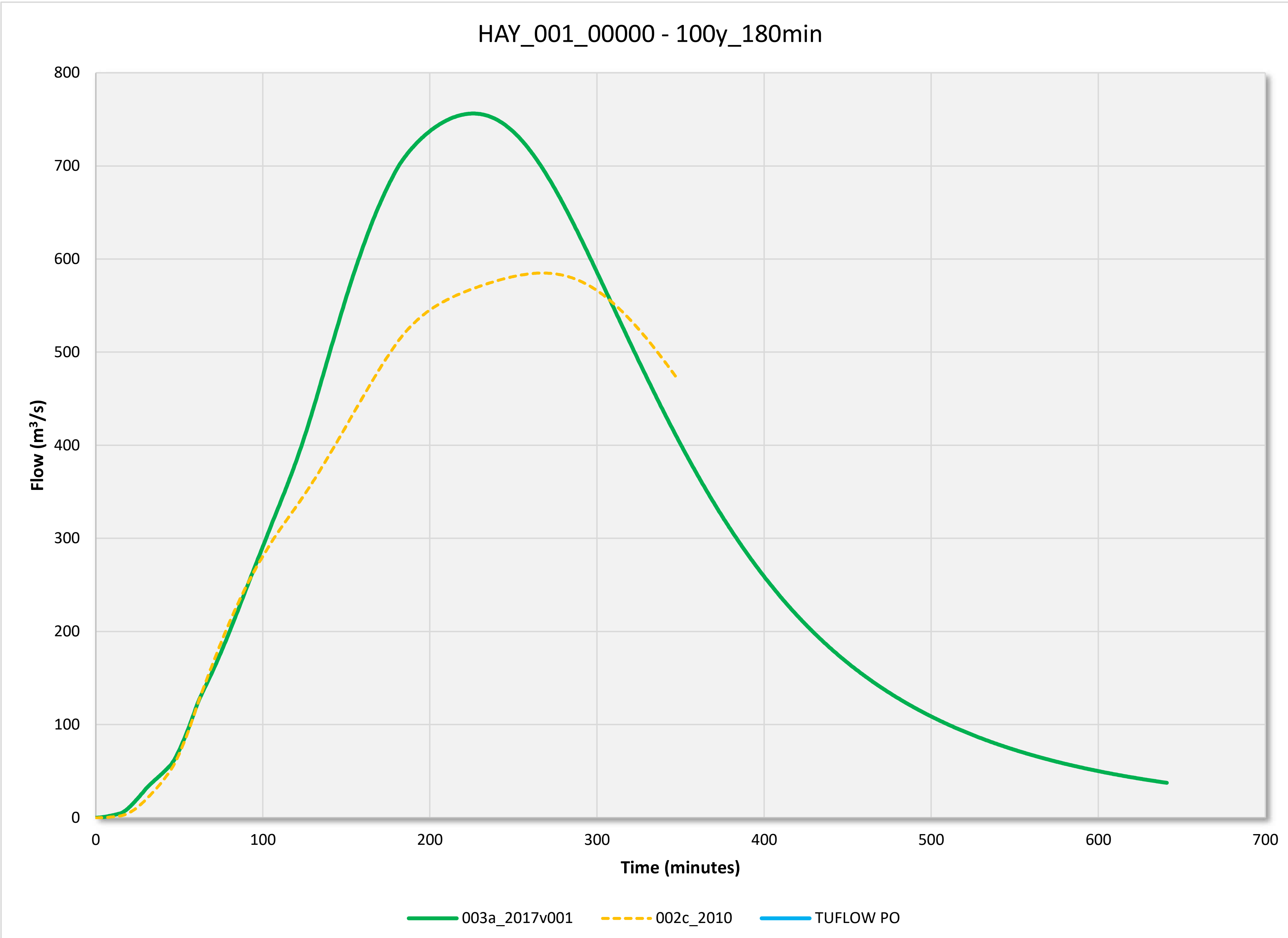

FMC_001_08327 - 20y_180min
Flow (m³/s)
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



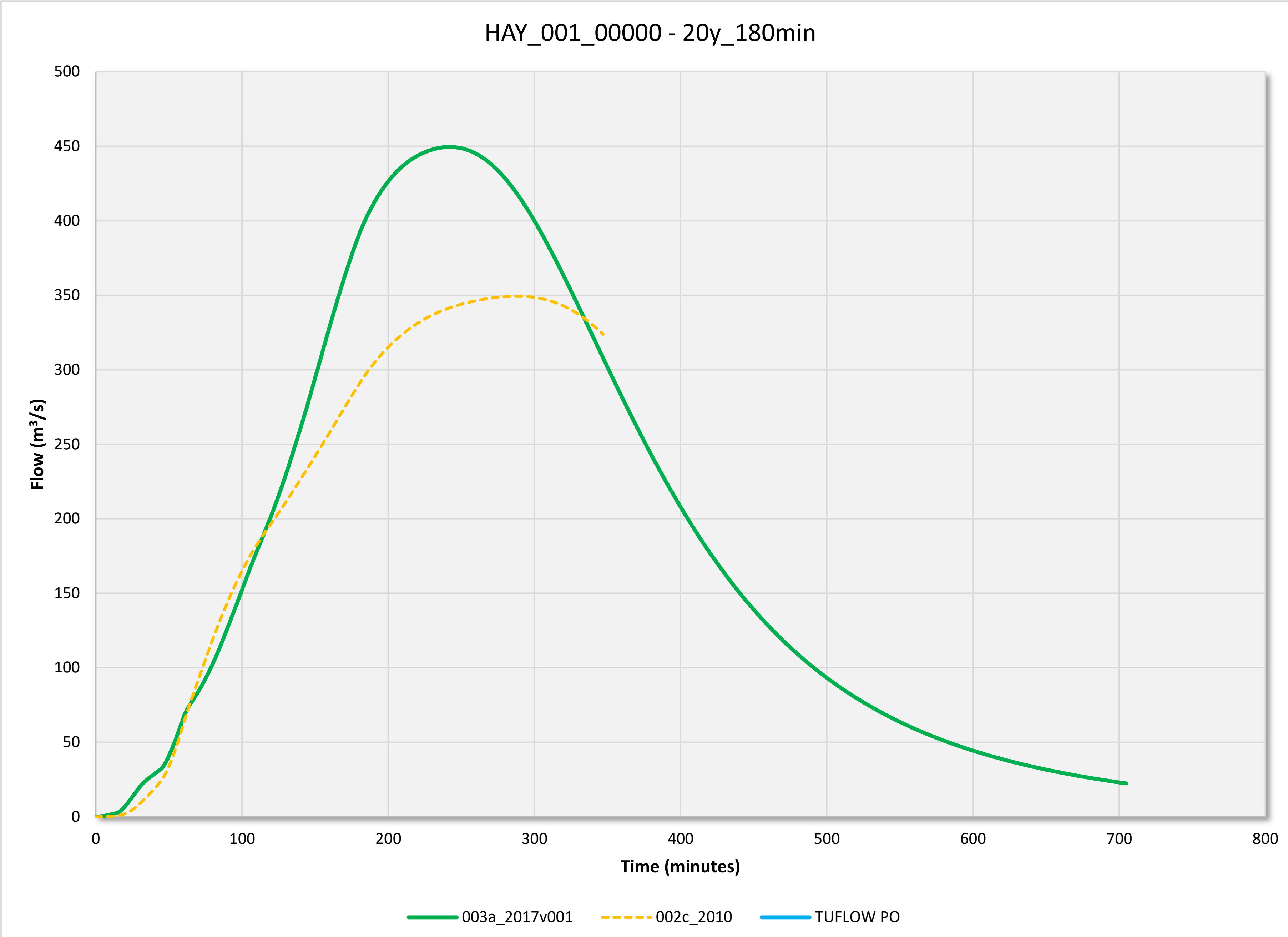
FWC_001_13248 - 100y_180min
Flow (m³/s)
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



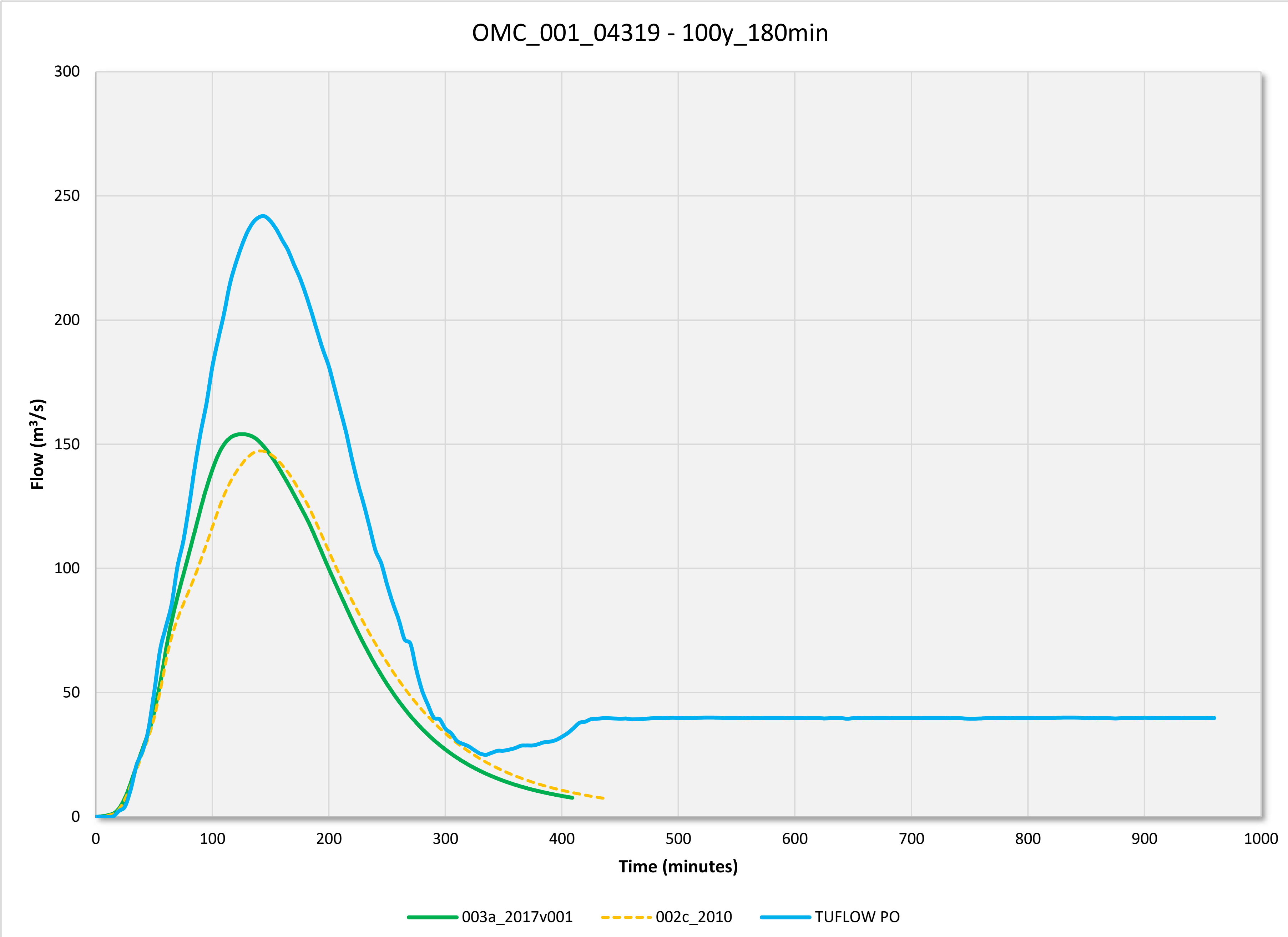
FWC_001_13248 - 20y_180min
Flow (m³/s)
50
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

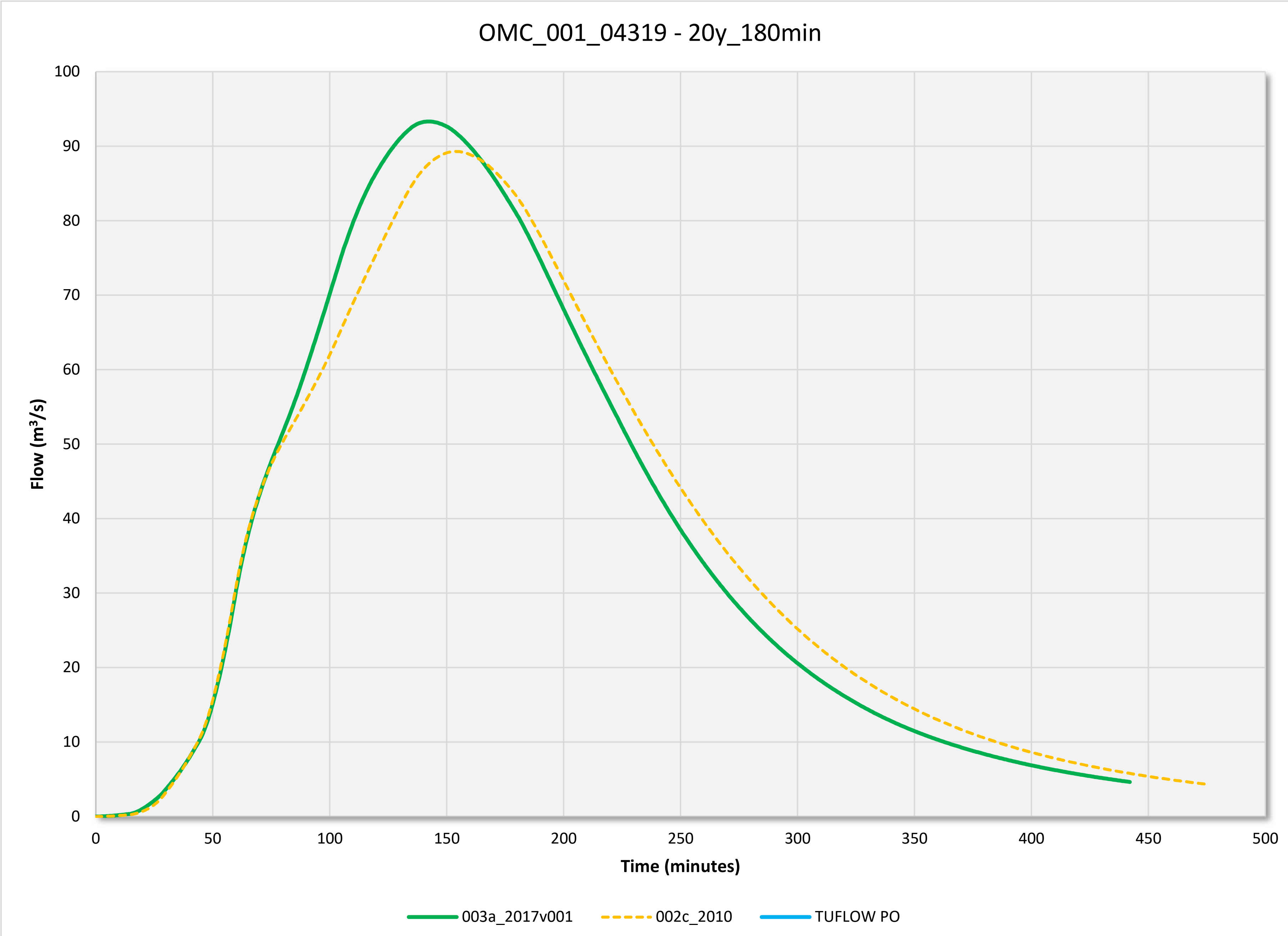


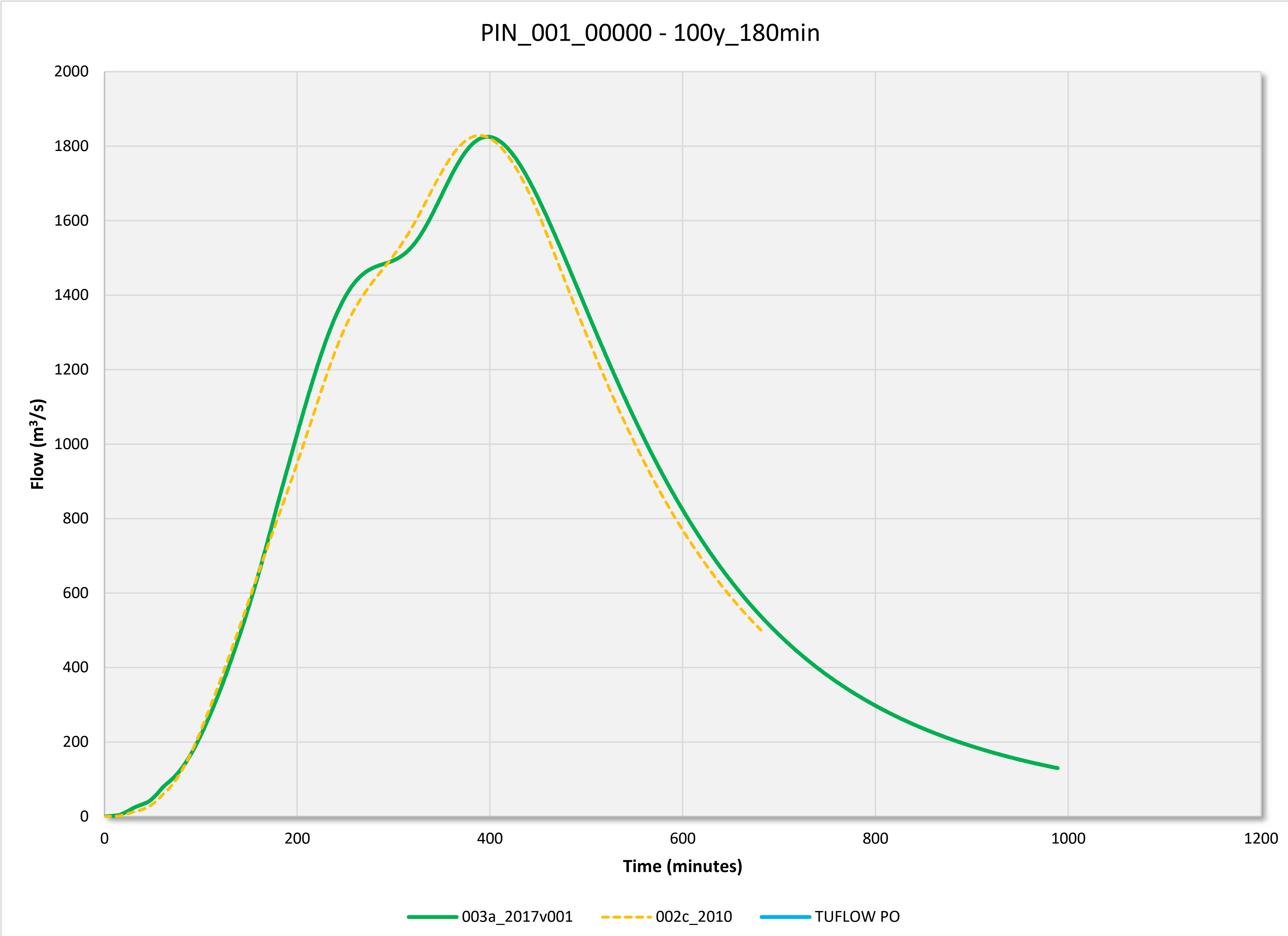
HAY_001_00000 - 100y_180min
Flow (m³/s)
0
100
200
300
400
500
600
700
800
Time (minutes)
0
100
200
300
400
500
600
700
003a_2017v001
002c_2010
TUFLOW PO



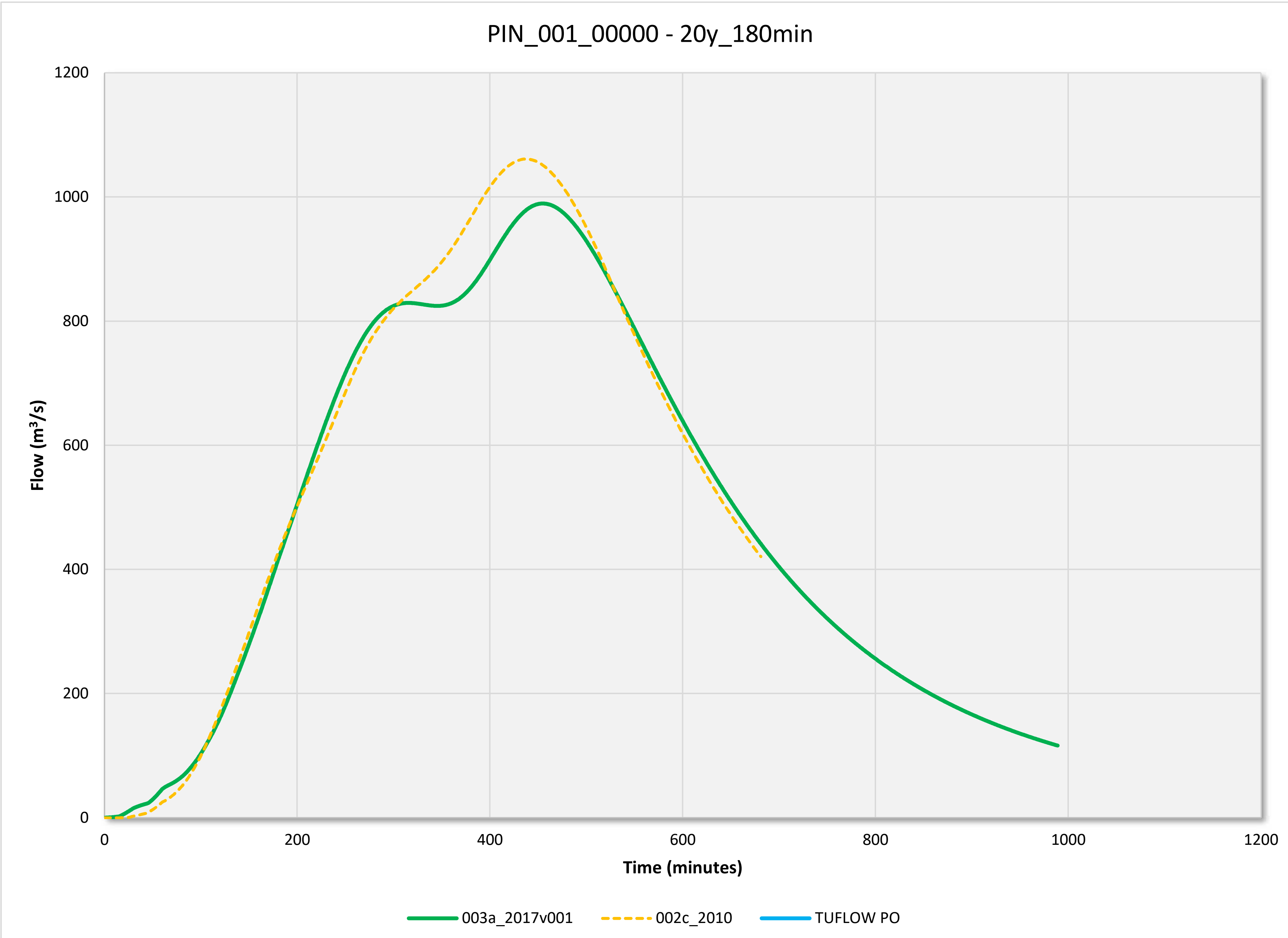
HAY_001_00000 - 20y_180min
Flow (m³/s)
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

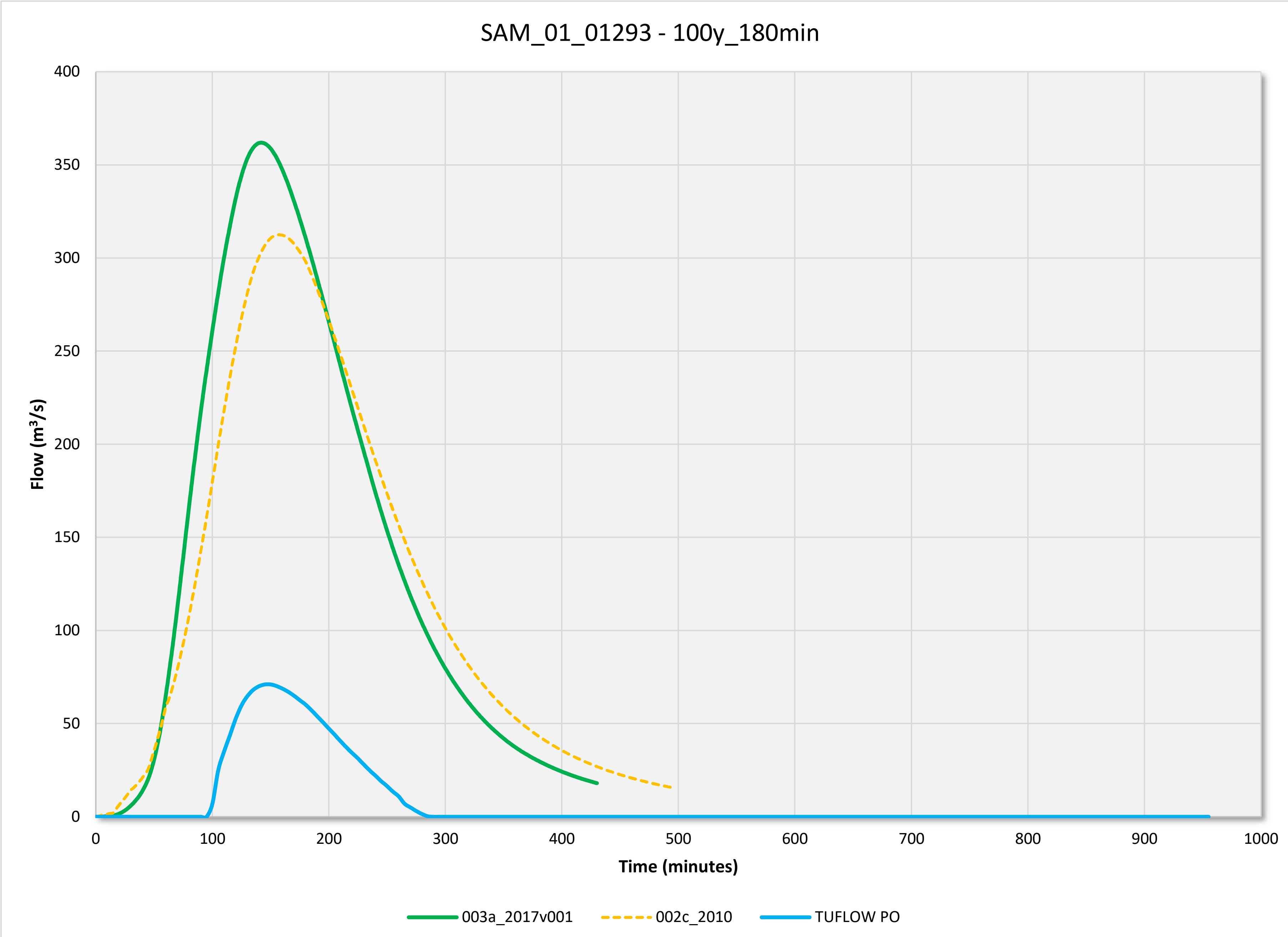

OMC_001_04319 - 100y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


OMC_001_04319 - 20y_180min
Flow (m³/s)
Time (minutes)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
400
450
500
003a_2017v001
002c_2010
TUFLOW PO

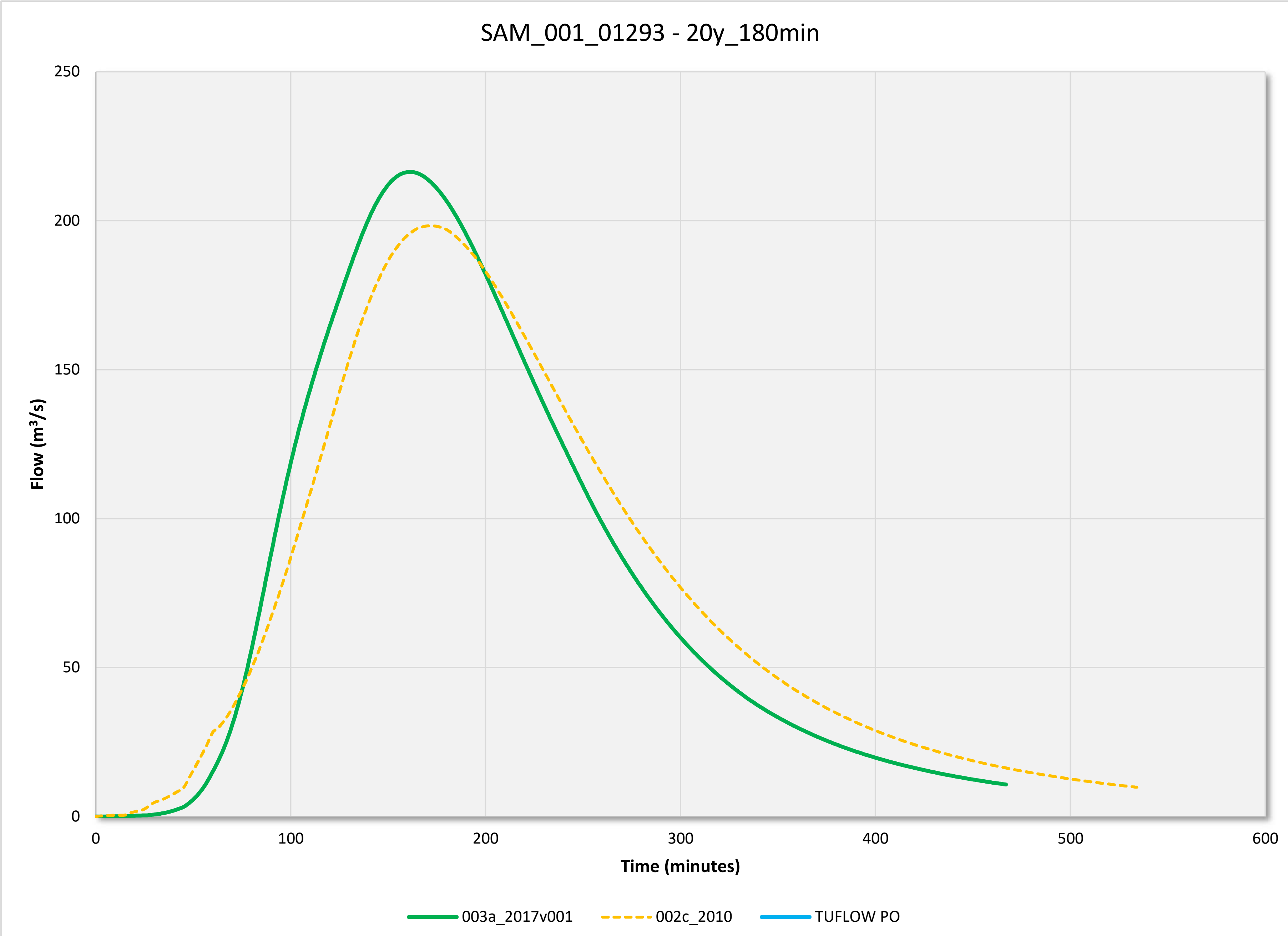


PIN_001_00000 - 100y_180min
Flow (m³/s)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

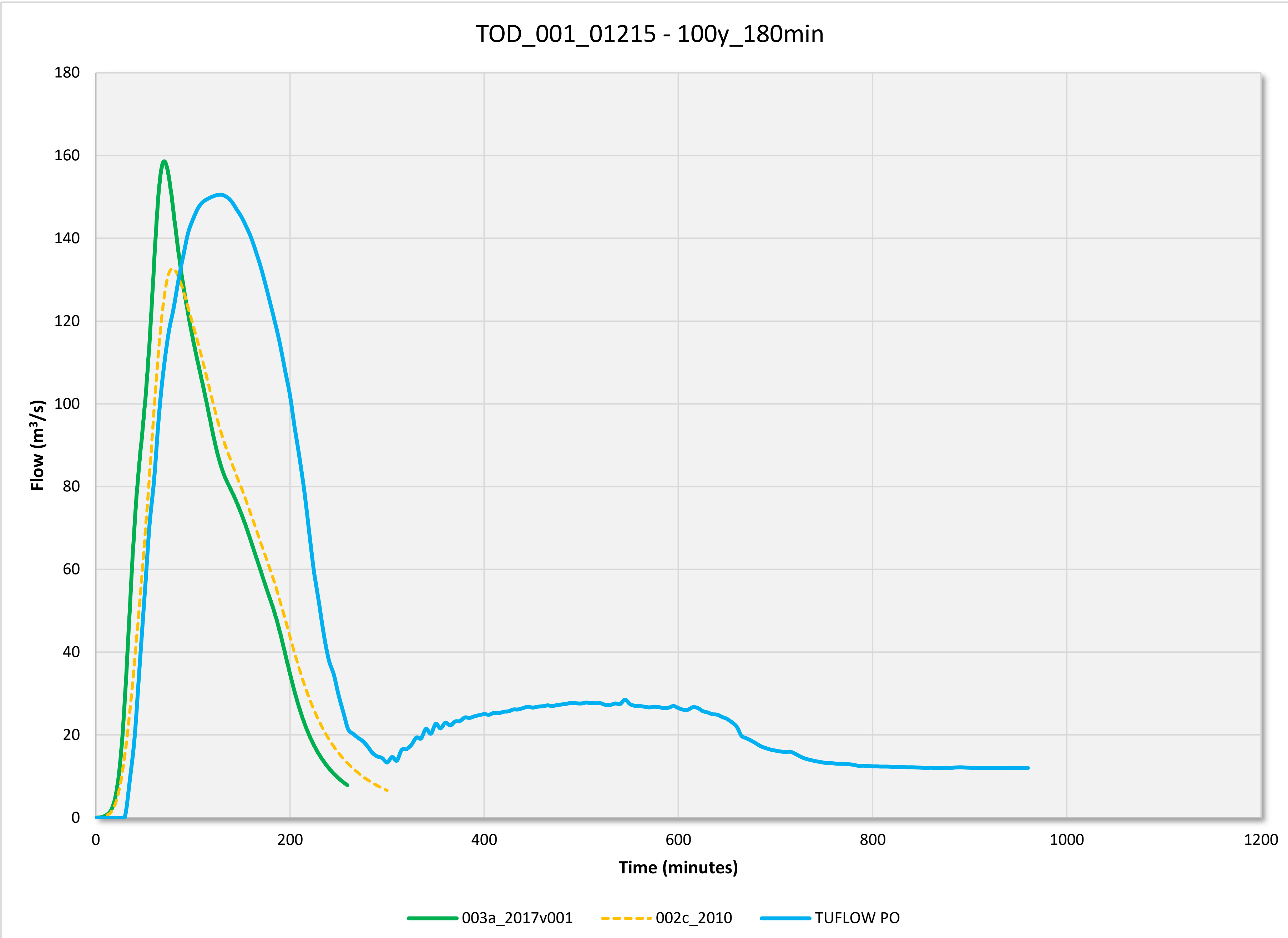

PIN_001_00000 - 20y_180min
Flow (m³/s)
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

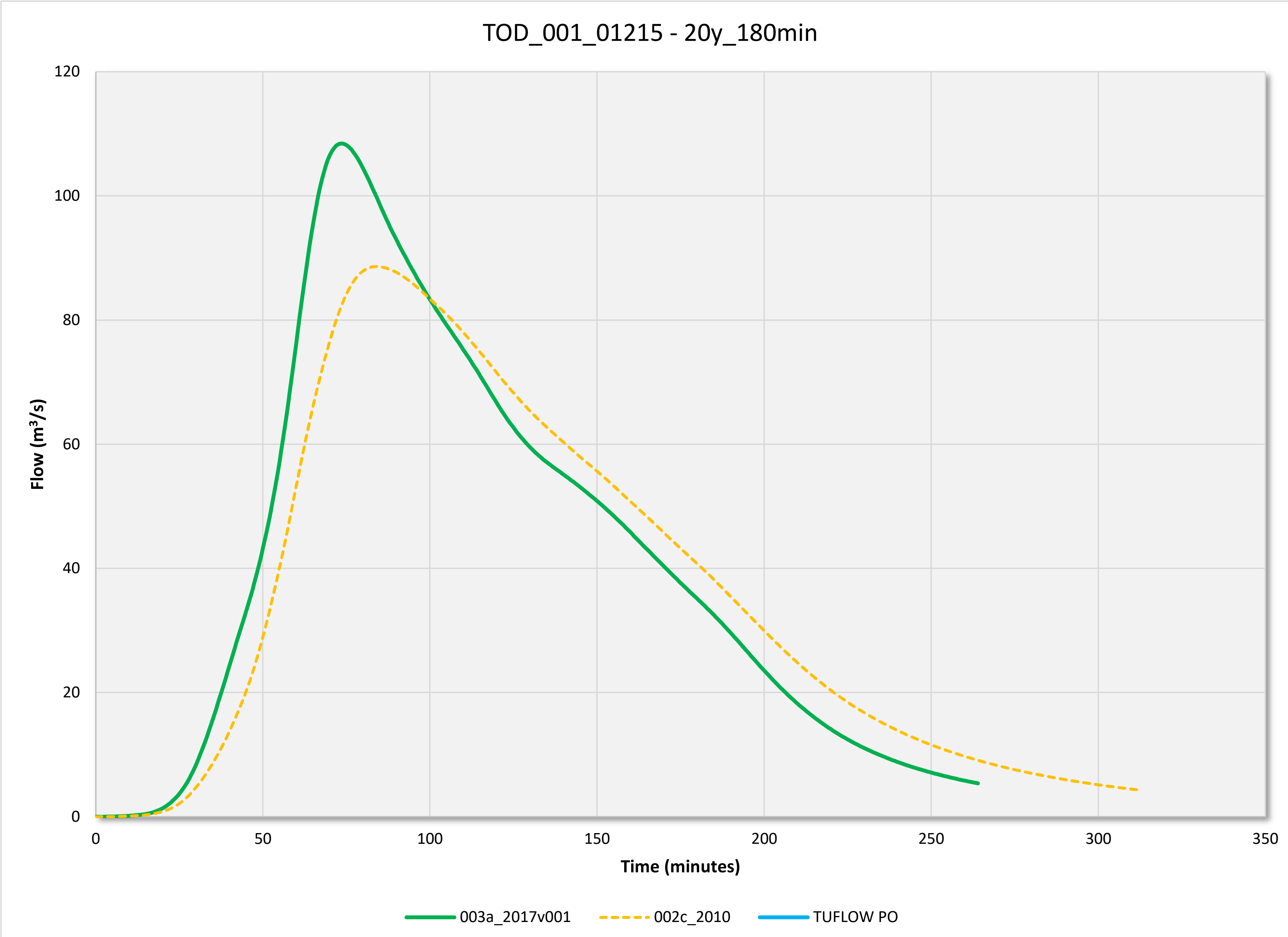


SAM_01_01293 - 100y_180min
Flow (m³/s)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

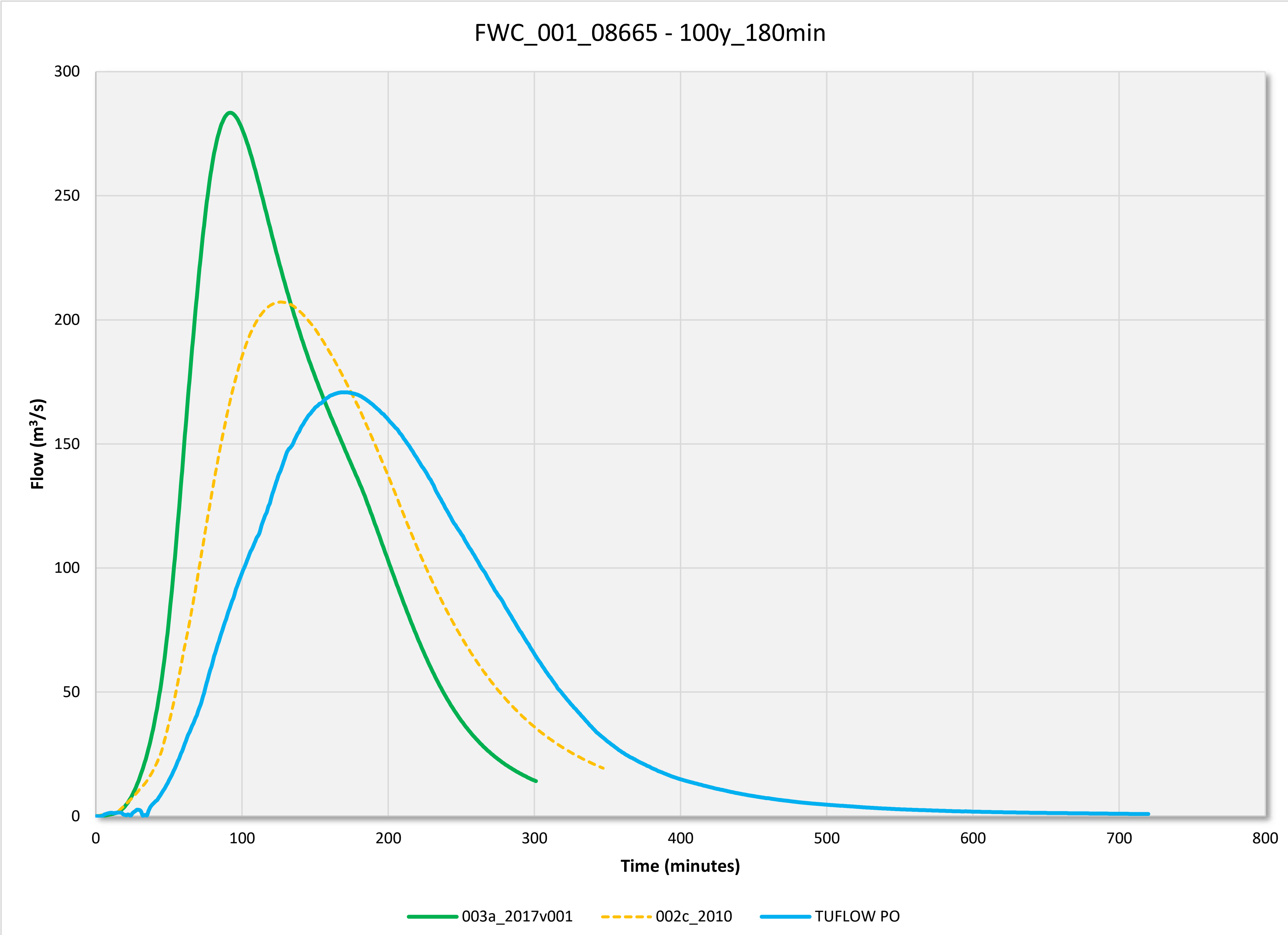


SAM_001_01293 - 20y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

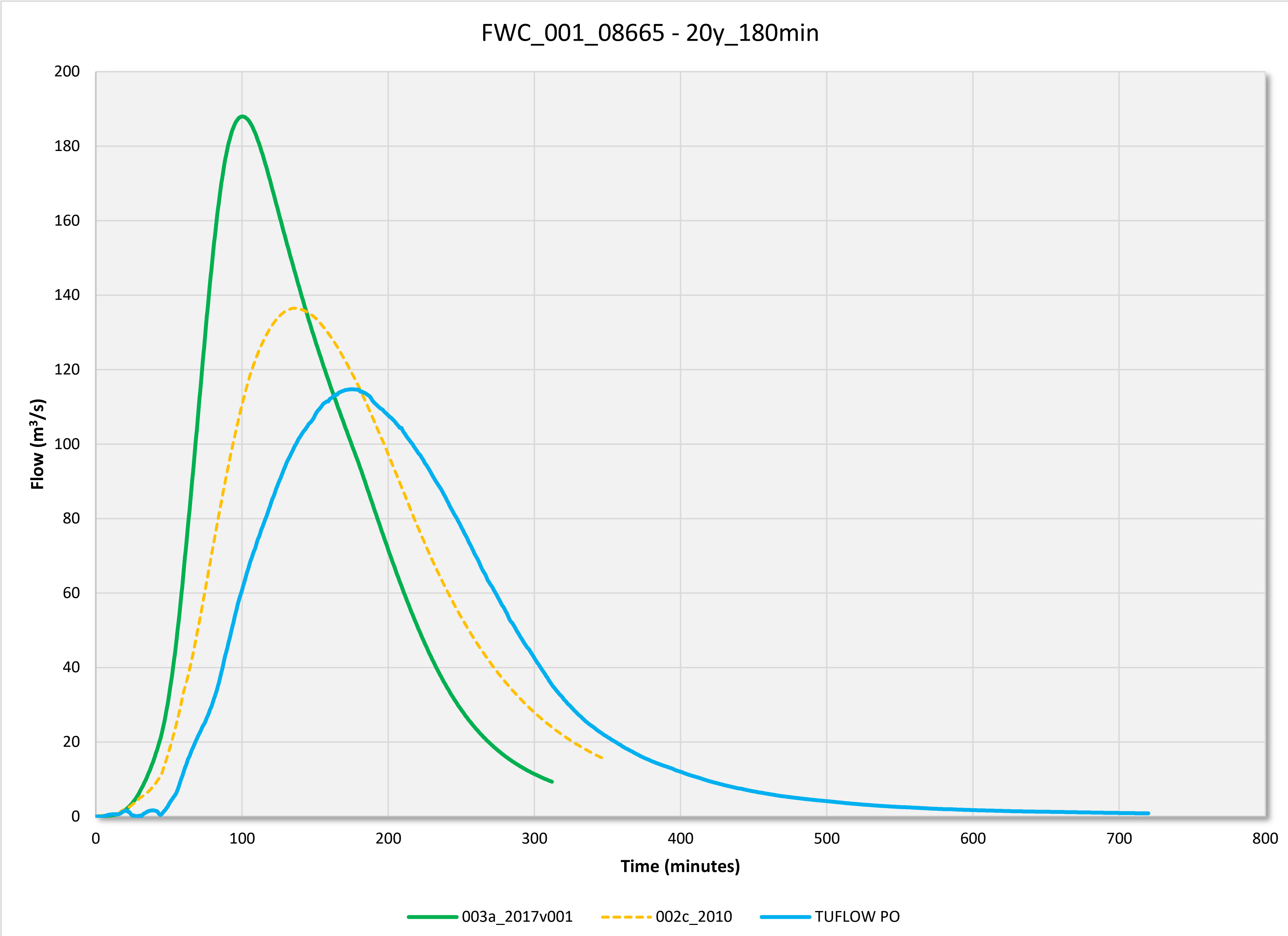

TOD_001_01215 - 100y_180min
Flow (m³/s)
0
20
40
60
80
100
120
140
160
180
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

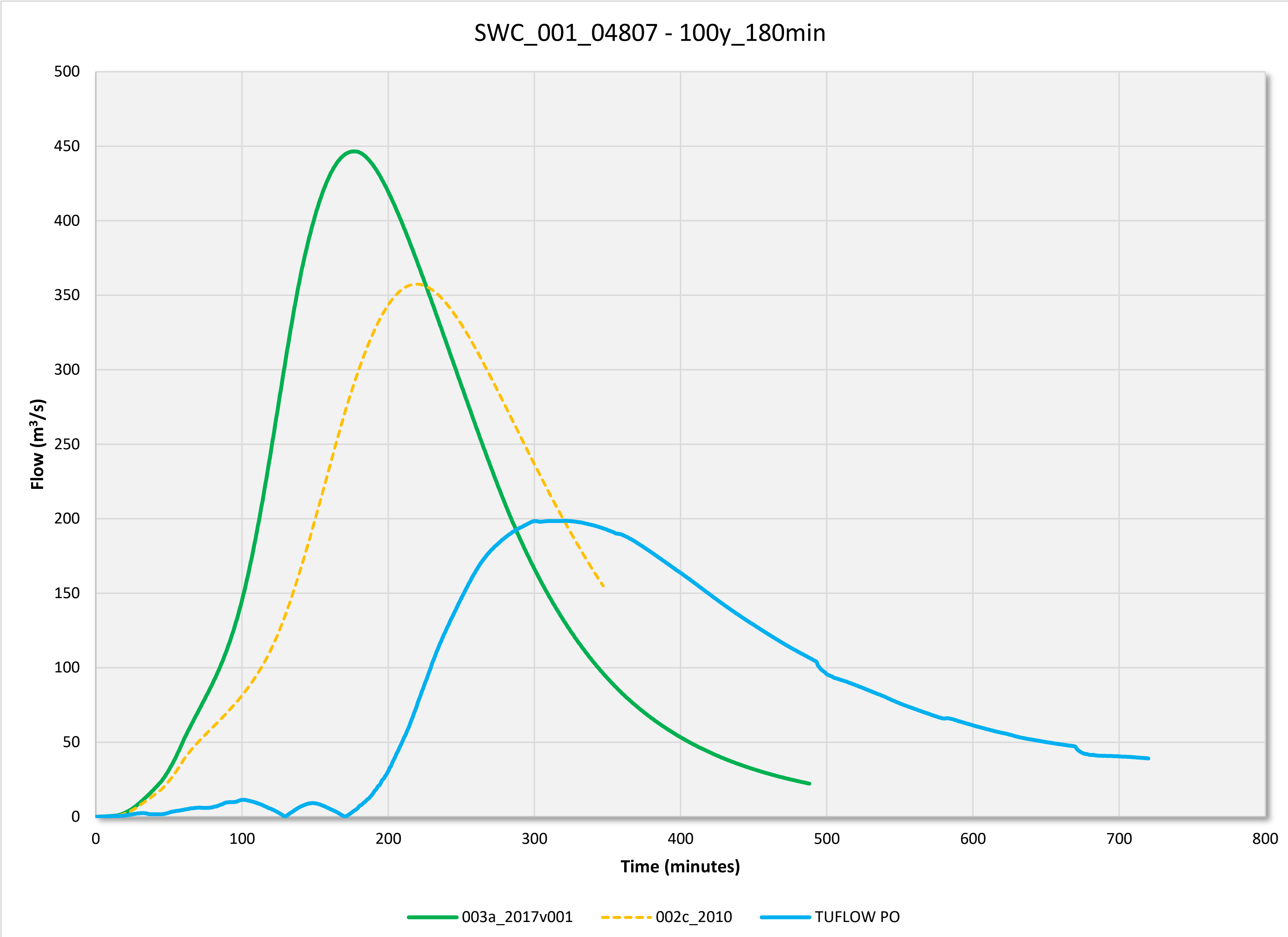


TOD_001_01215 - 20y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
003a_2017v001
002c_2010
TUFLOW PO

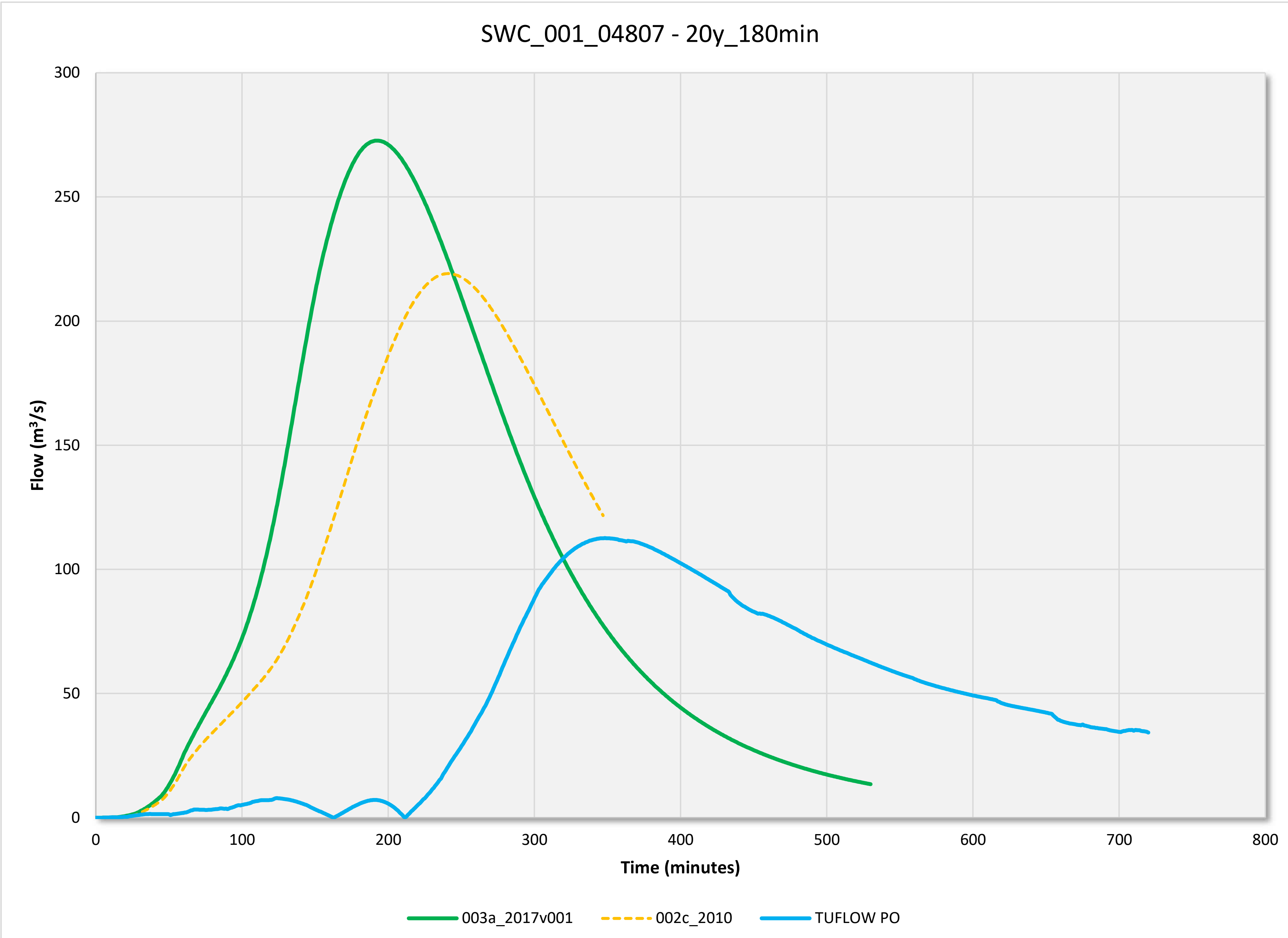


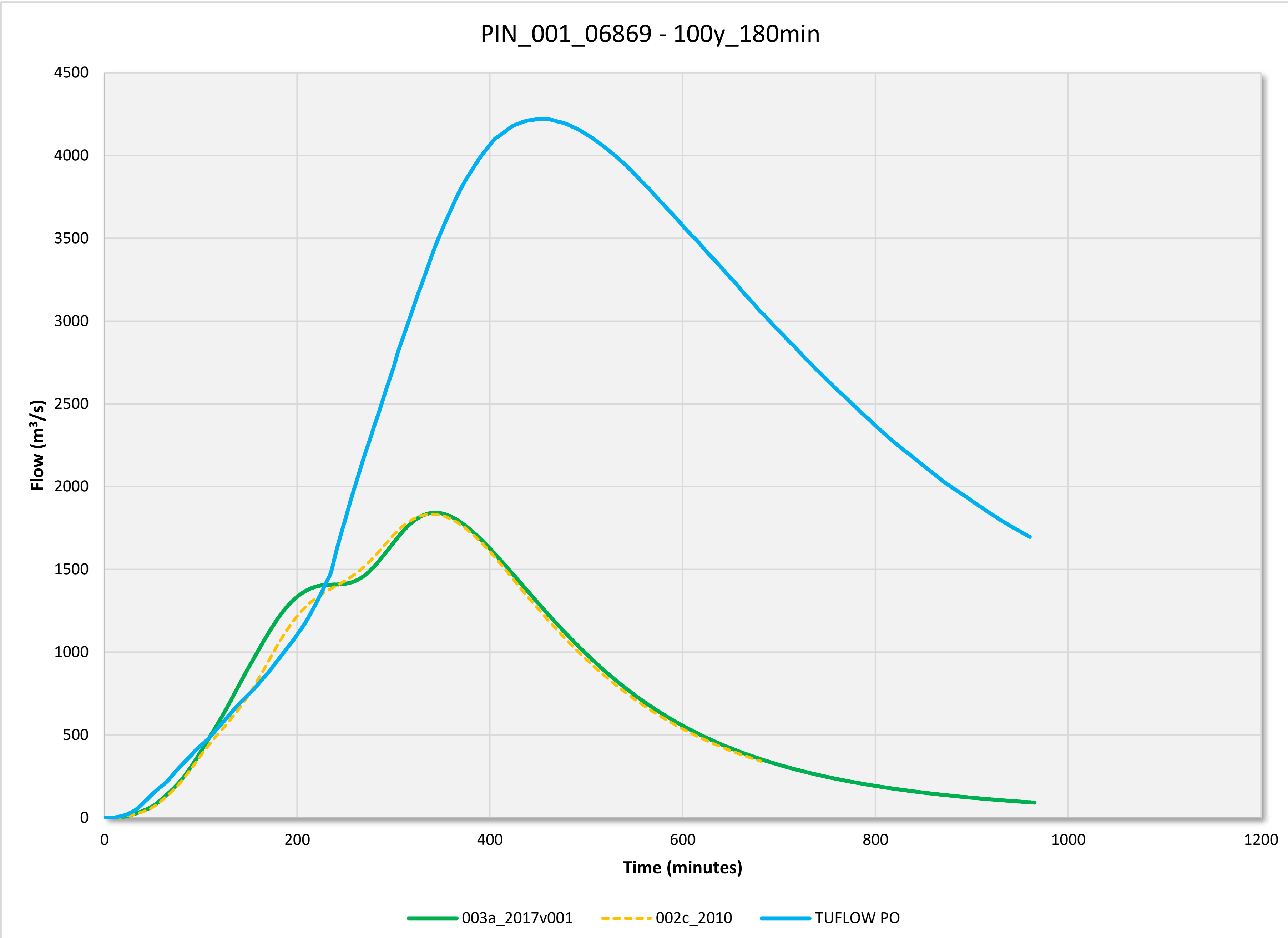
FWC_001_08665 - 100y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

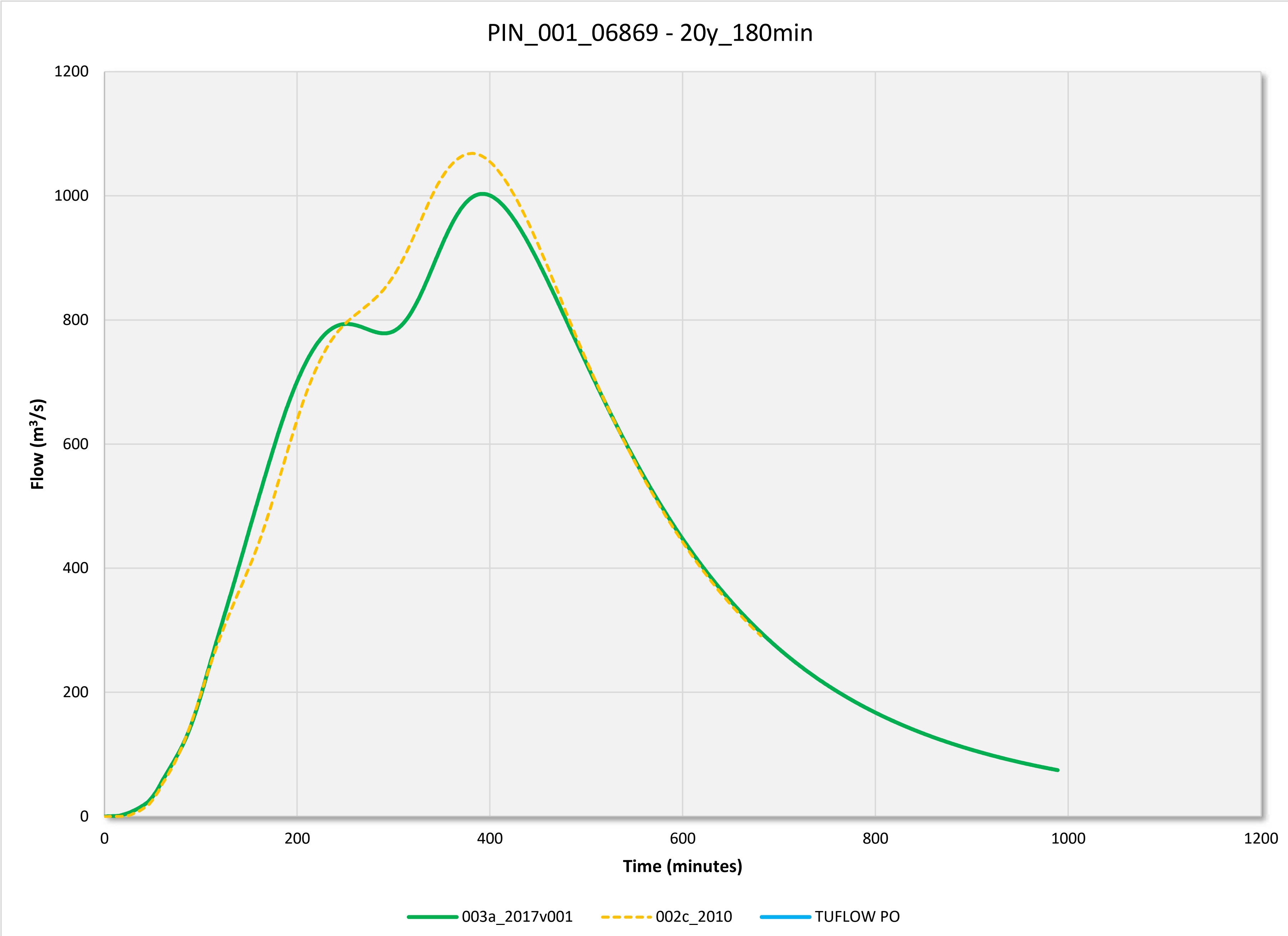

FWC_001_08665 - 20y_180min
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

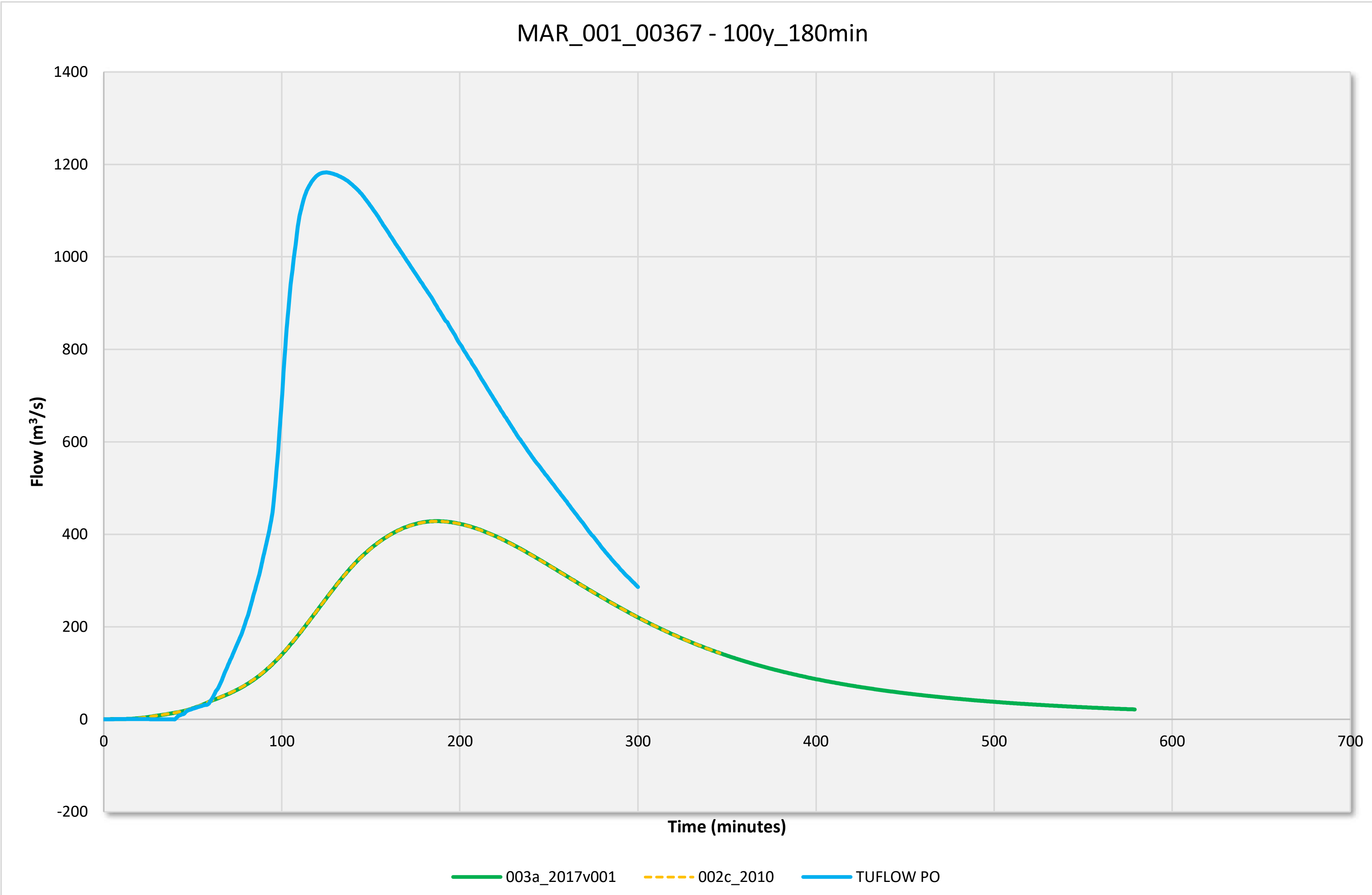


SWC_001_04807 - 100y_180min
Flow (m³/s)
500
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

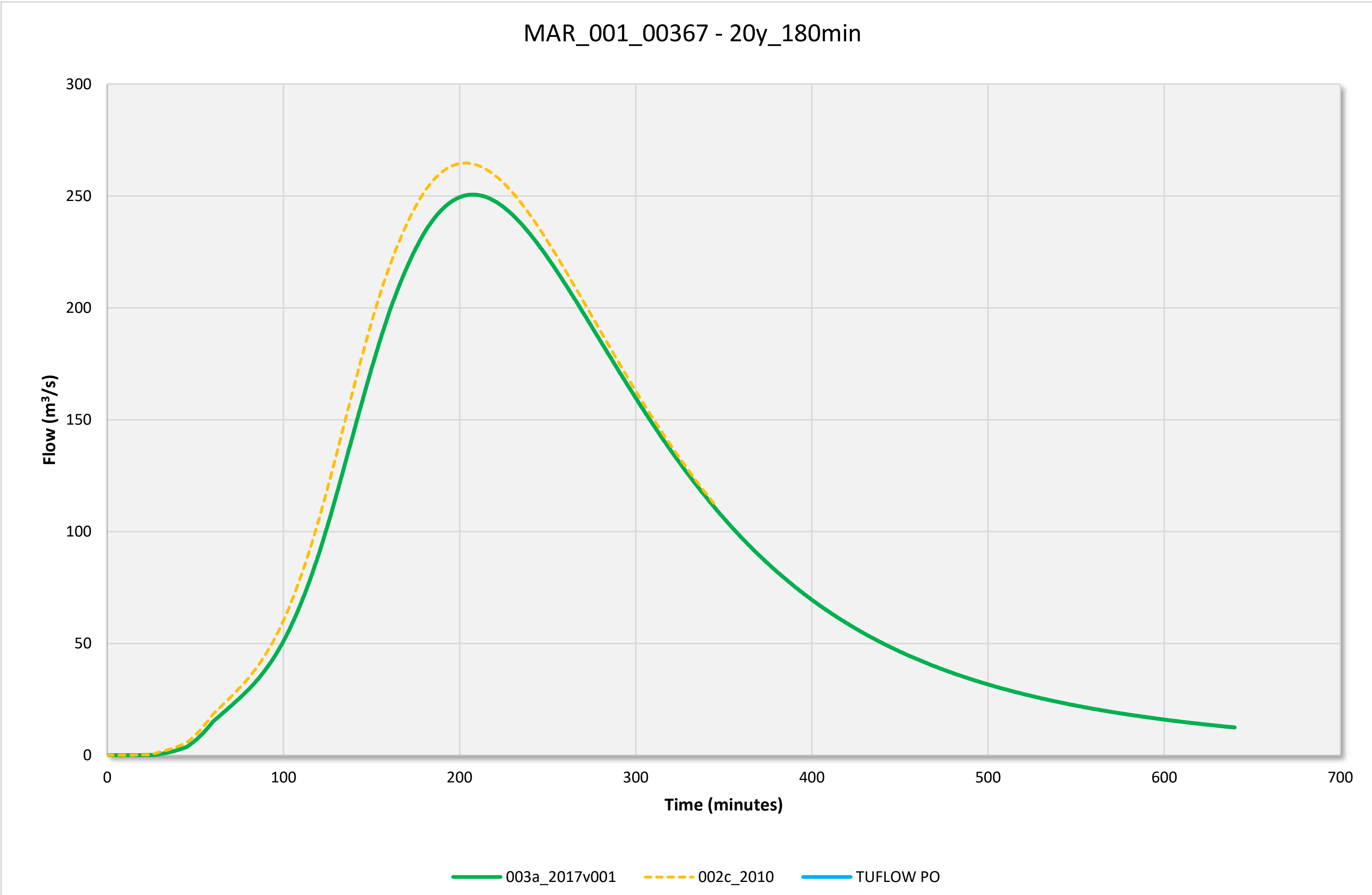

SWC_001_04807 - 20y_180min
Flow (m³/s)
0
50
100
150
200
250
300
Time (minutes)
0
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO


PIN_001_06869 - 100y_180min
Flow (m³/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

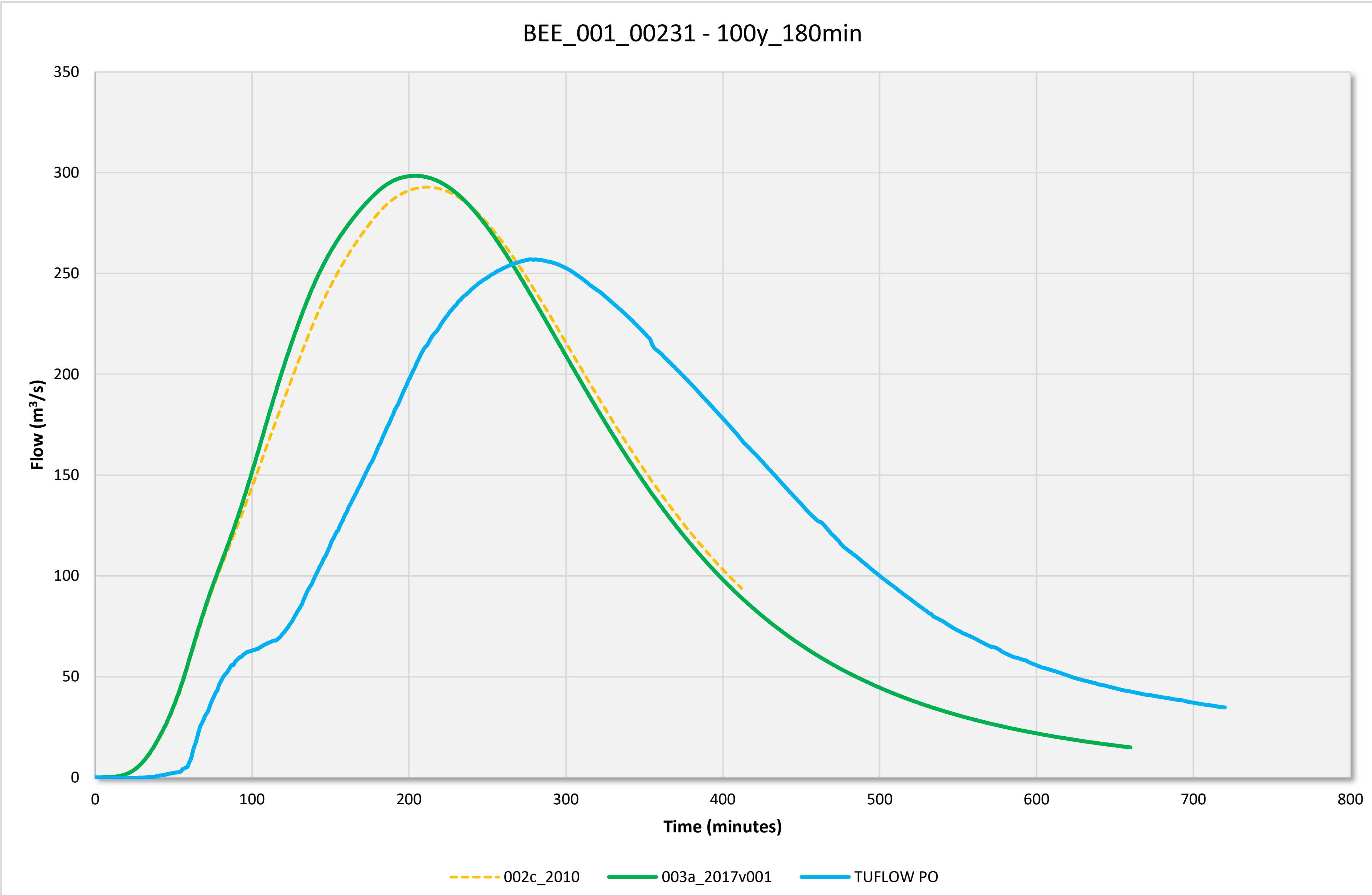

PIN_001_06869 - 20y_180min
Flow (m³/s)
0
200
400
600
800
1000
1200
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



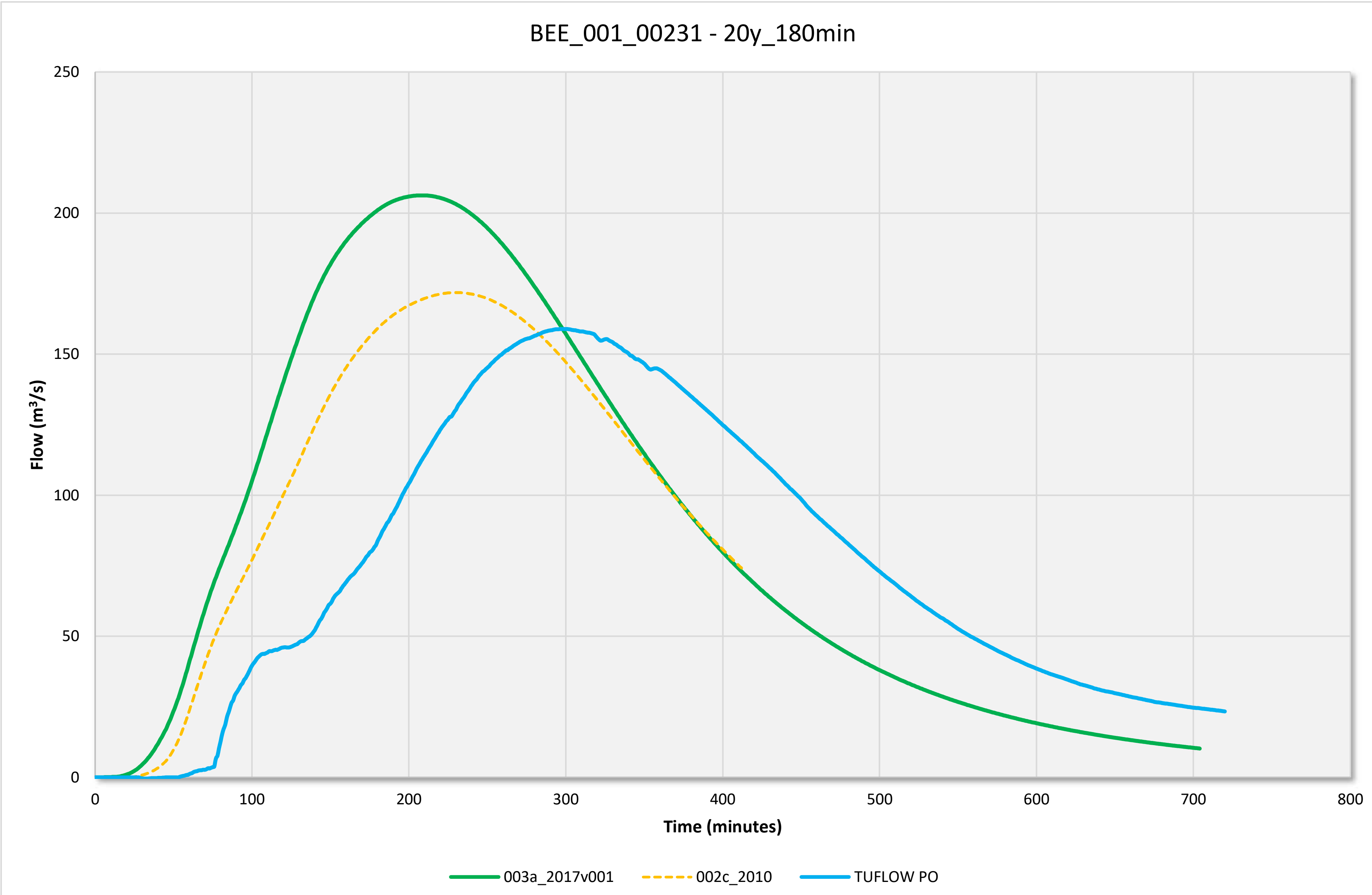
MAR_001_00367 - 100y_180min
Flow (m³/s)
1400
1200
1000
800
600
400
200
0
-200
0
100
200
300
400
500
600
700
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

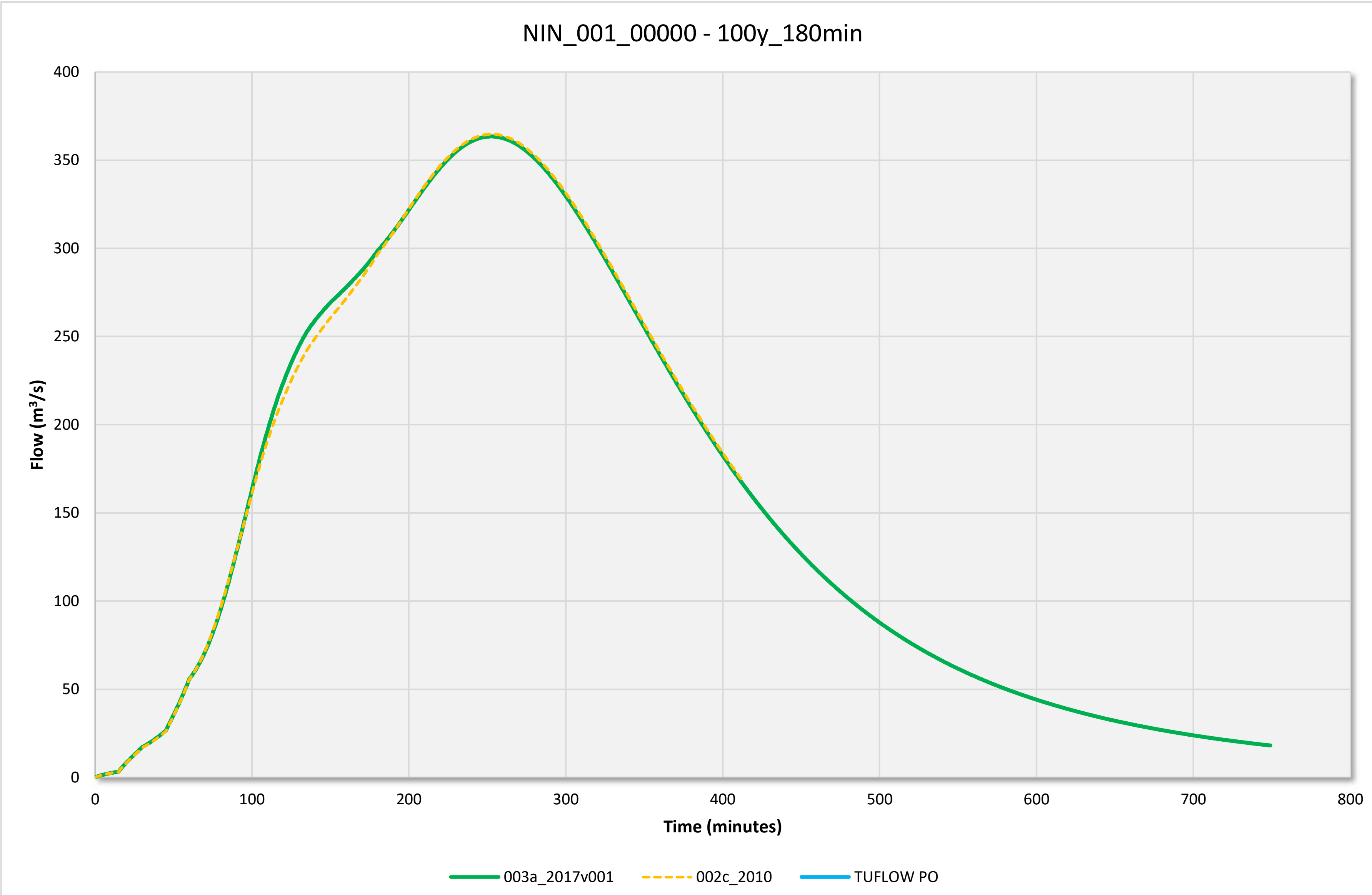


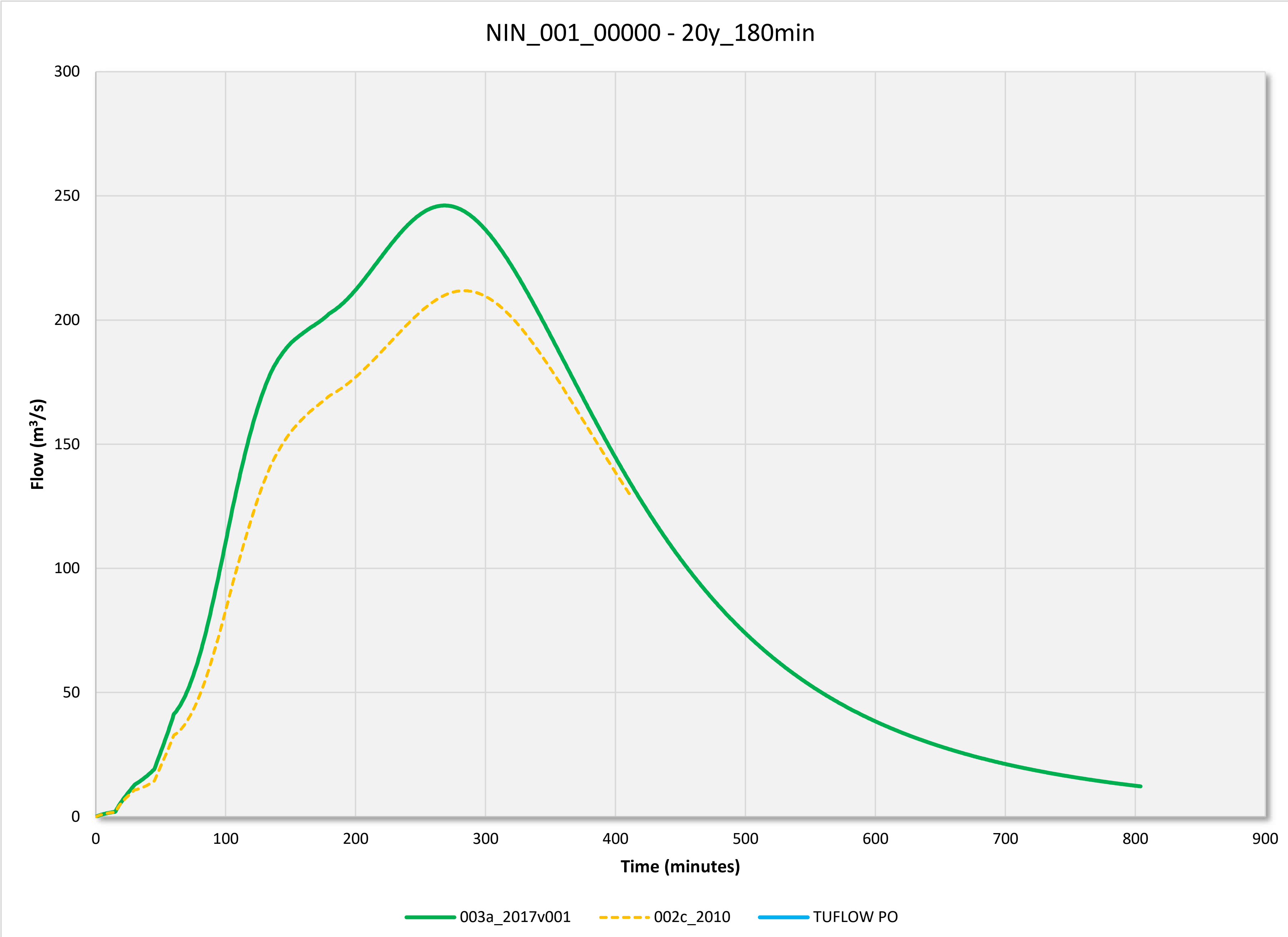
MAR_001_00367 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

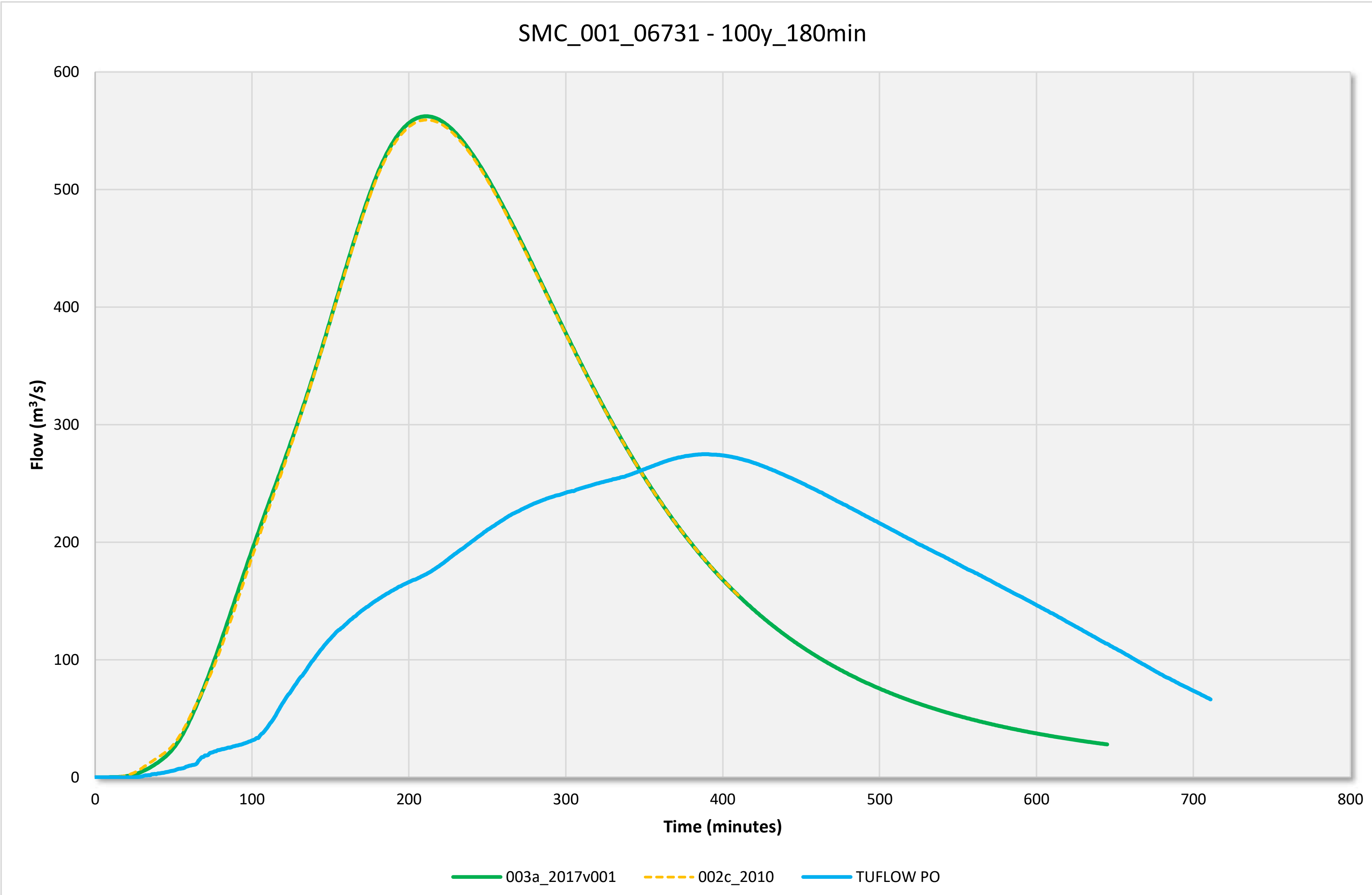


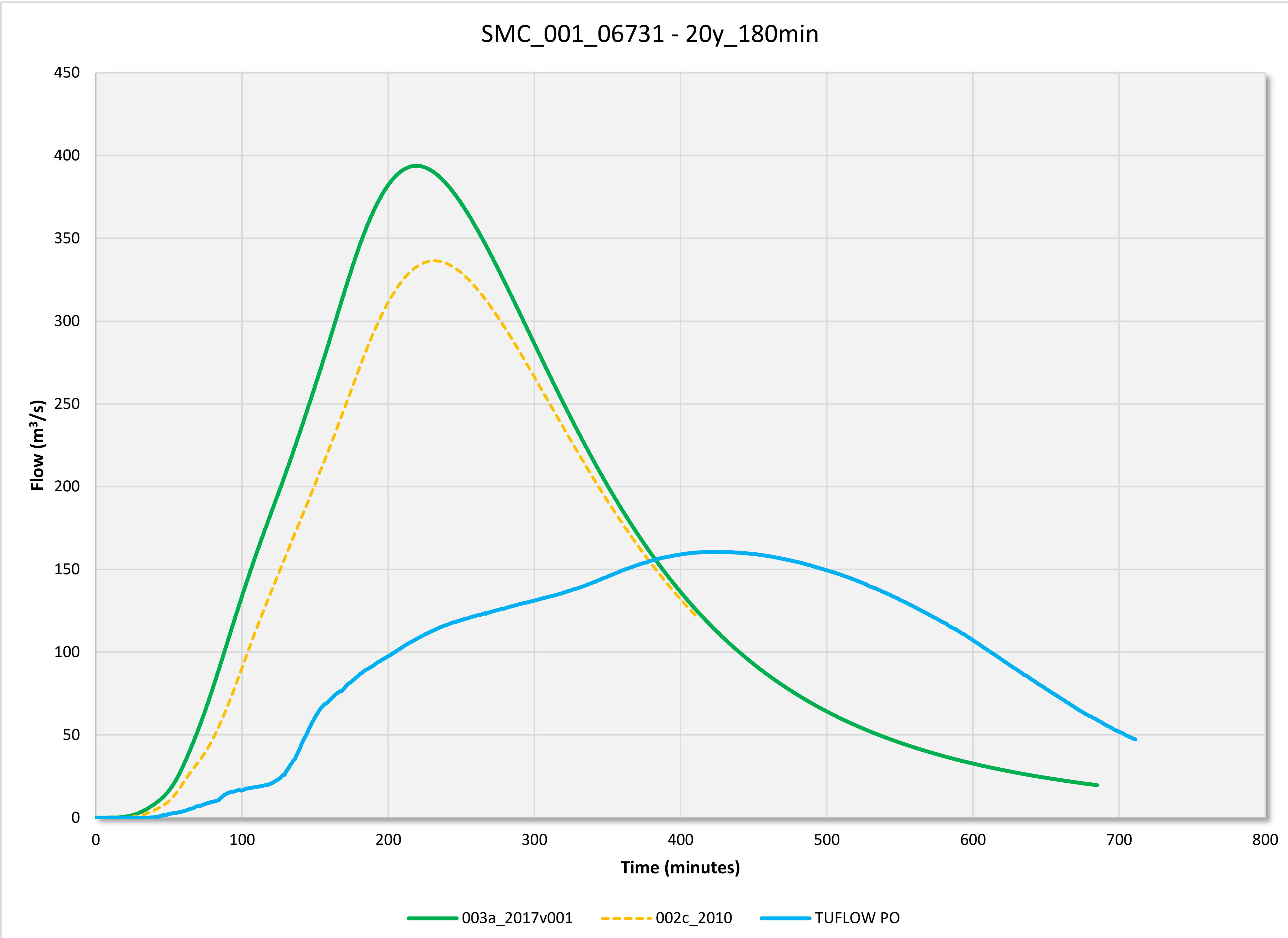
BEE_001_00231 - 100y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600
700
800
002c_2010
003a_2017v001
TUFLOW PO

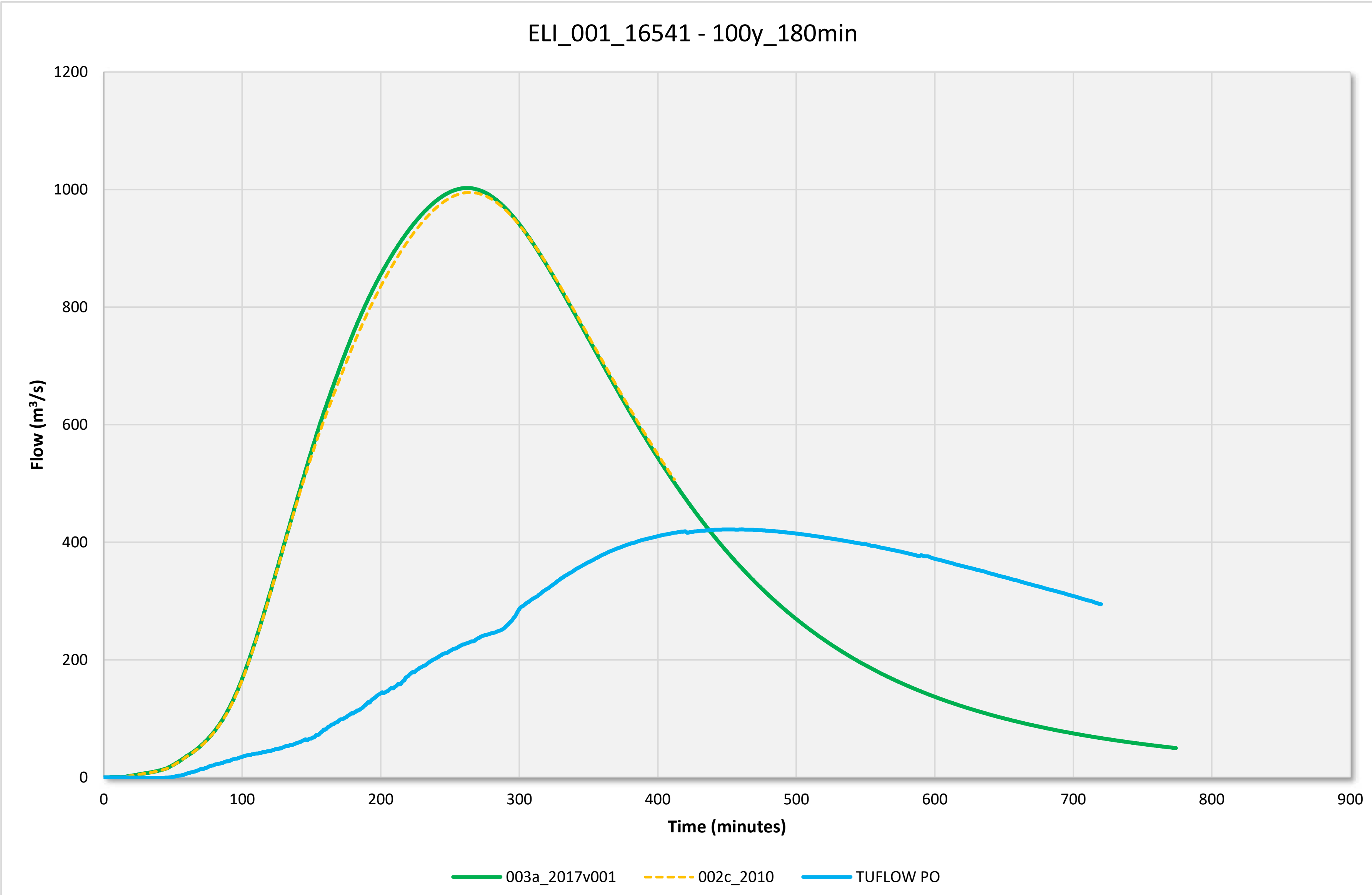

BEE_001_00231 - 20y_180min
Flow (m³/s)
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


NIN_001_00000 - 100y_180min
Flow (m³/s)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

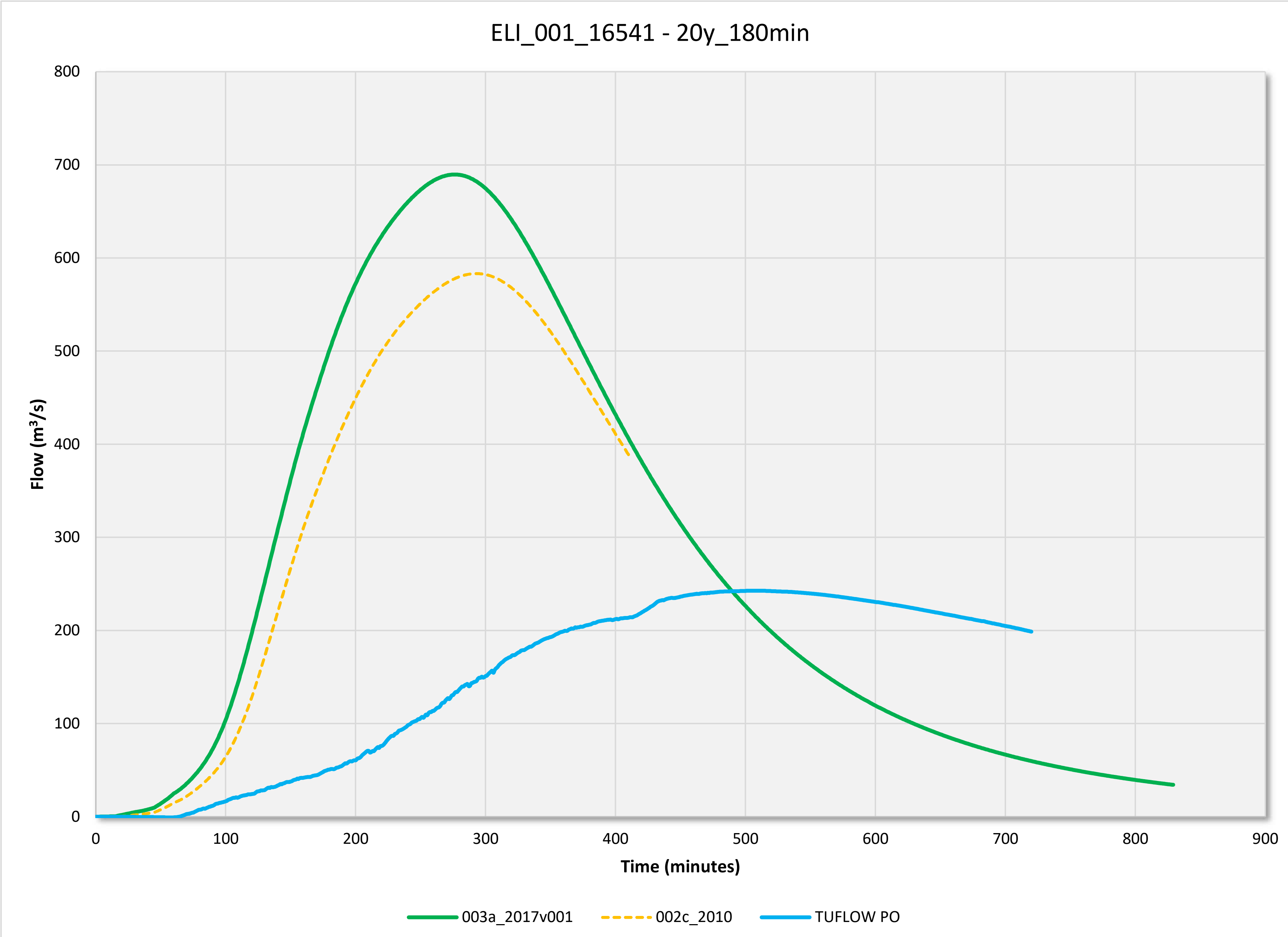

NIN_001_00000 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

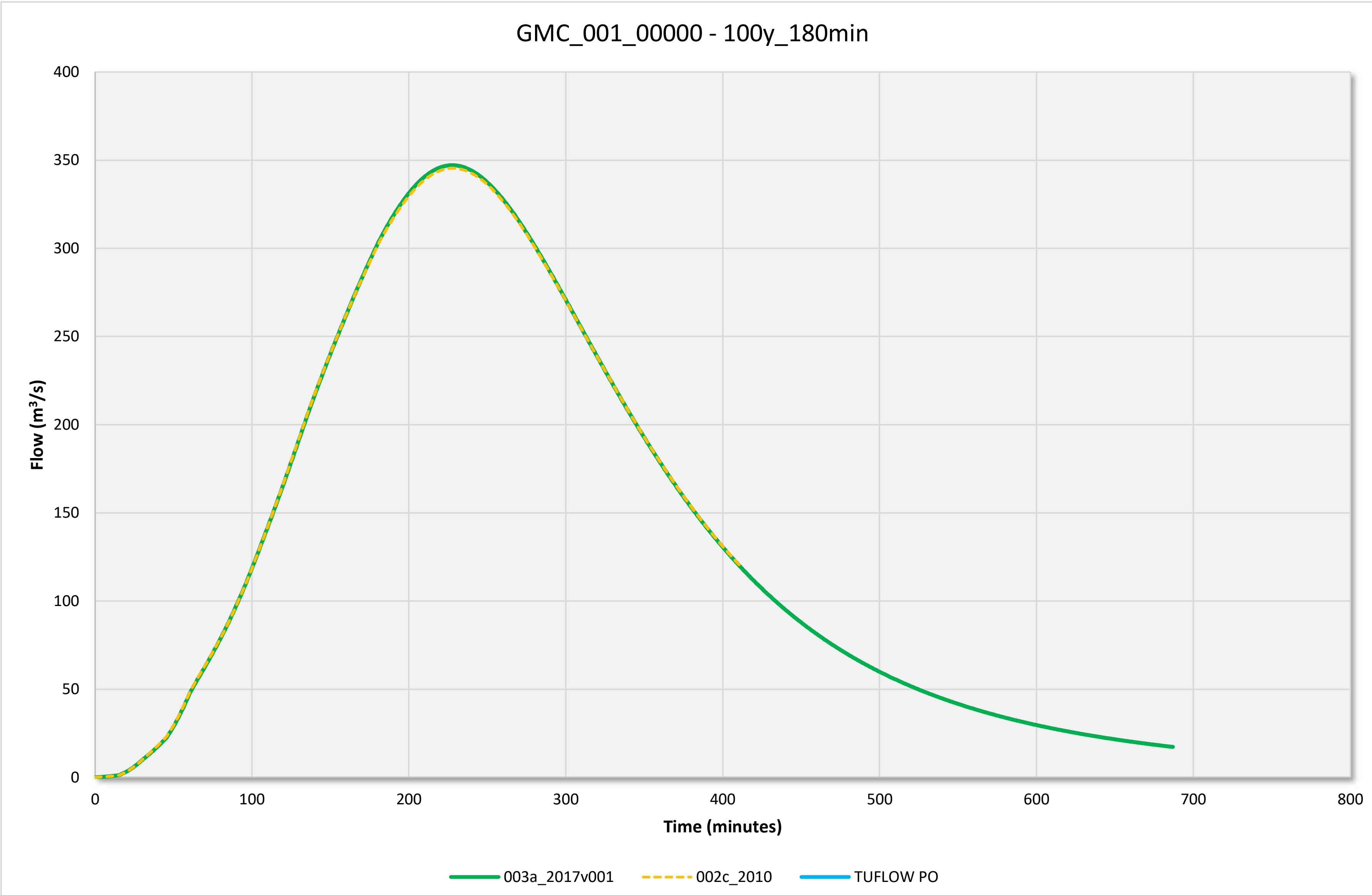

SMC_001_06731 - 100y_180min
Flow (m³/s)
0
100
200
300
400
500
600
Time (minutes)
0
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO


SMC_001_06731 - 20y_180min
Flow (m³/s)
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

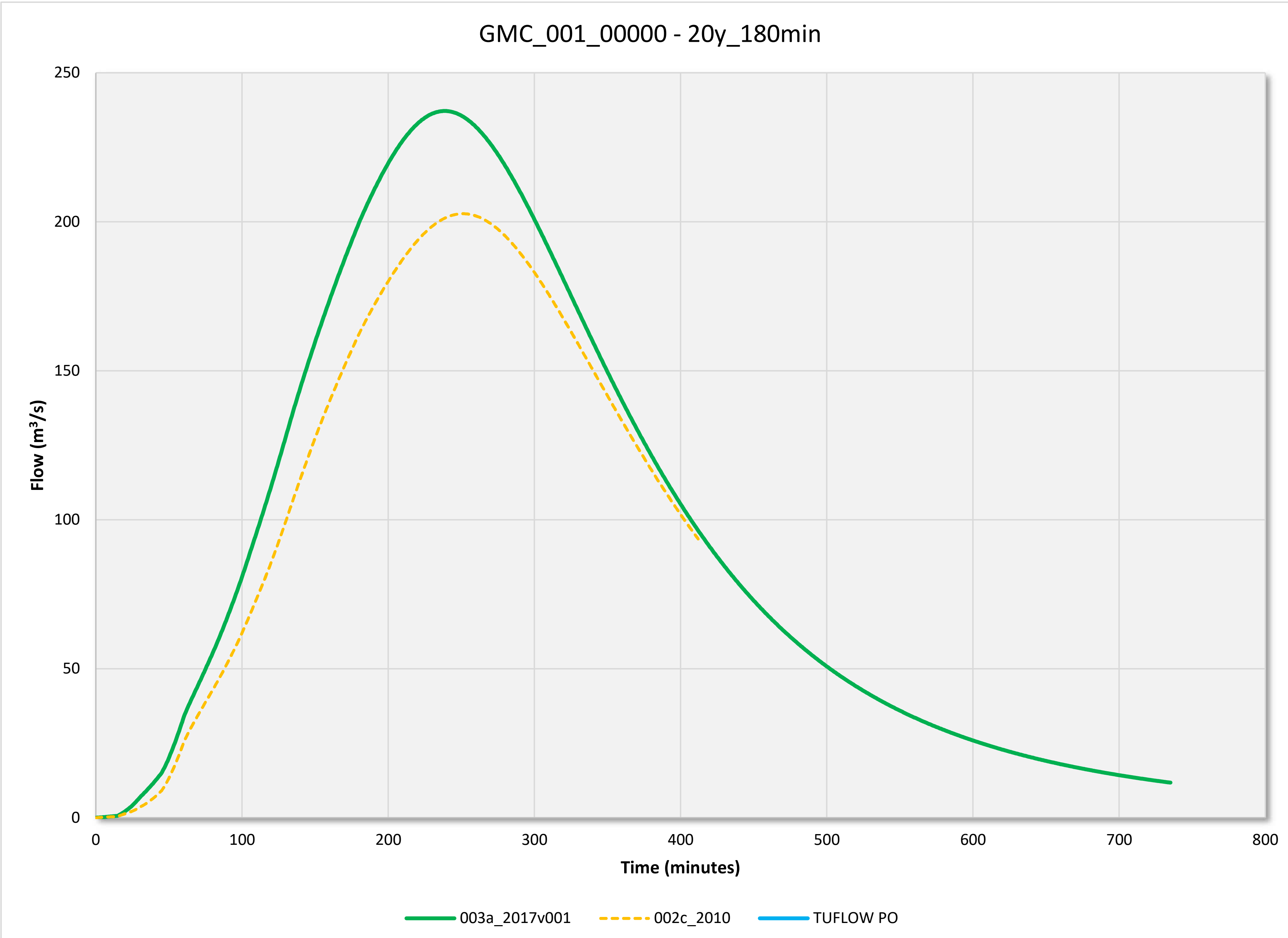


ELI_001_16541 - 100y_180min
Flow (m³/s)
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

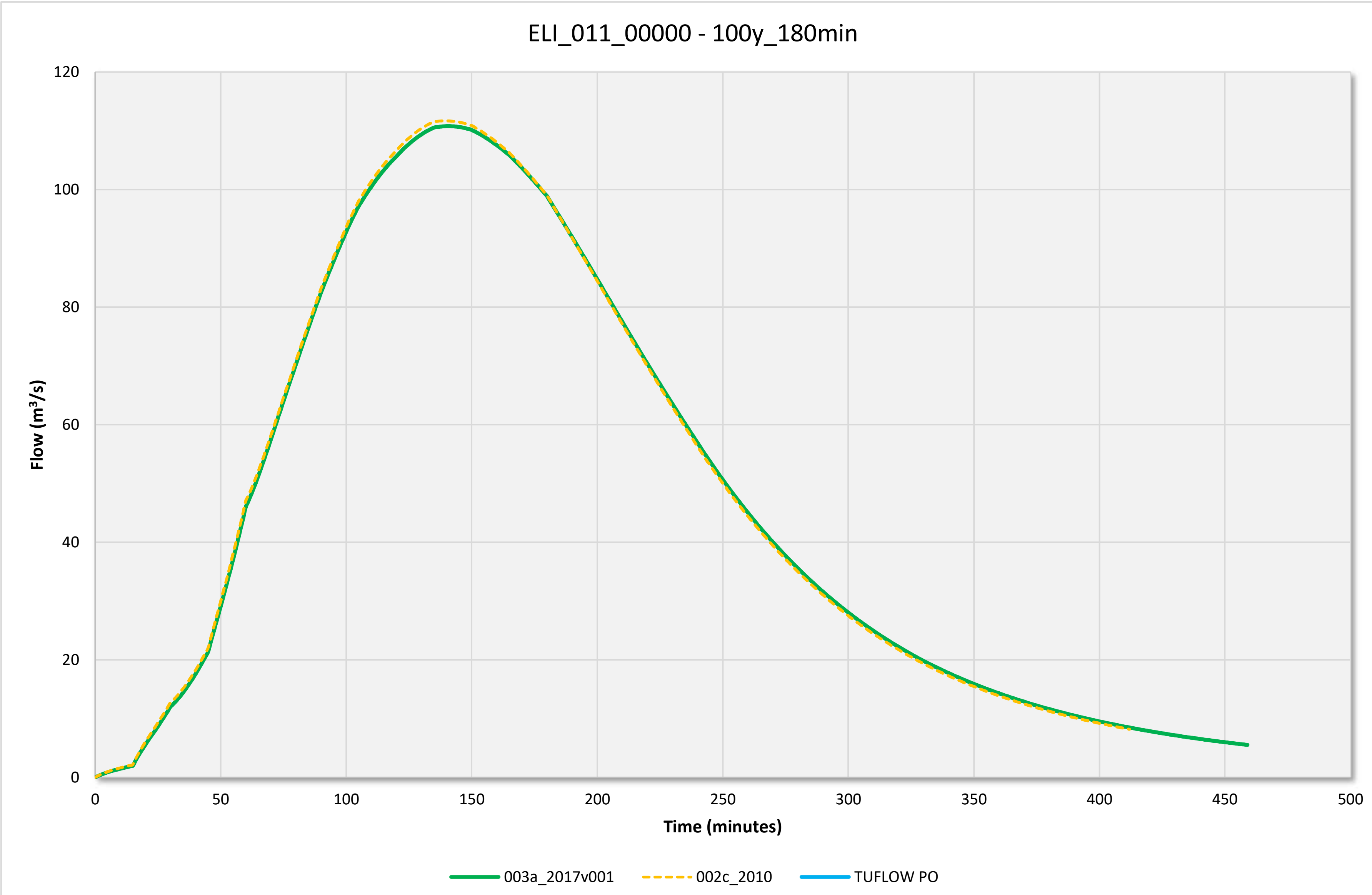

ELI_001_16541 - 20y_180min
Flow (m³/s)
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



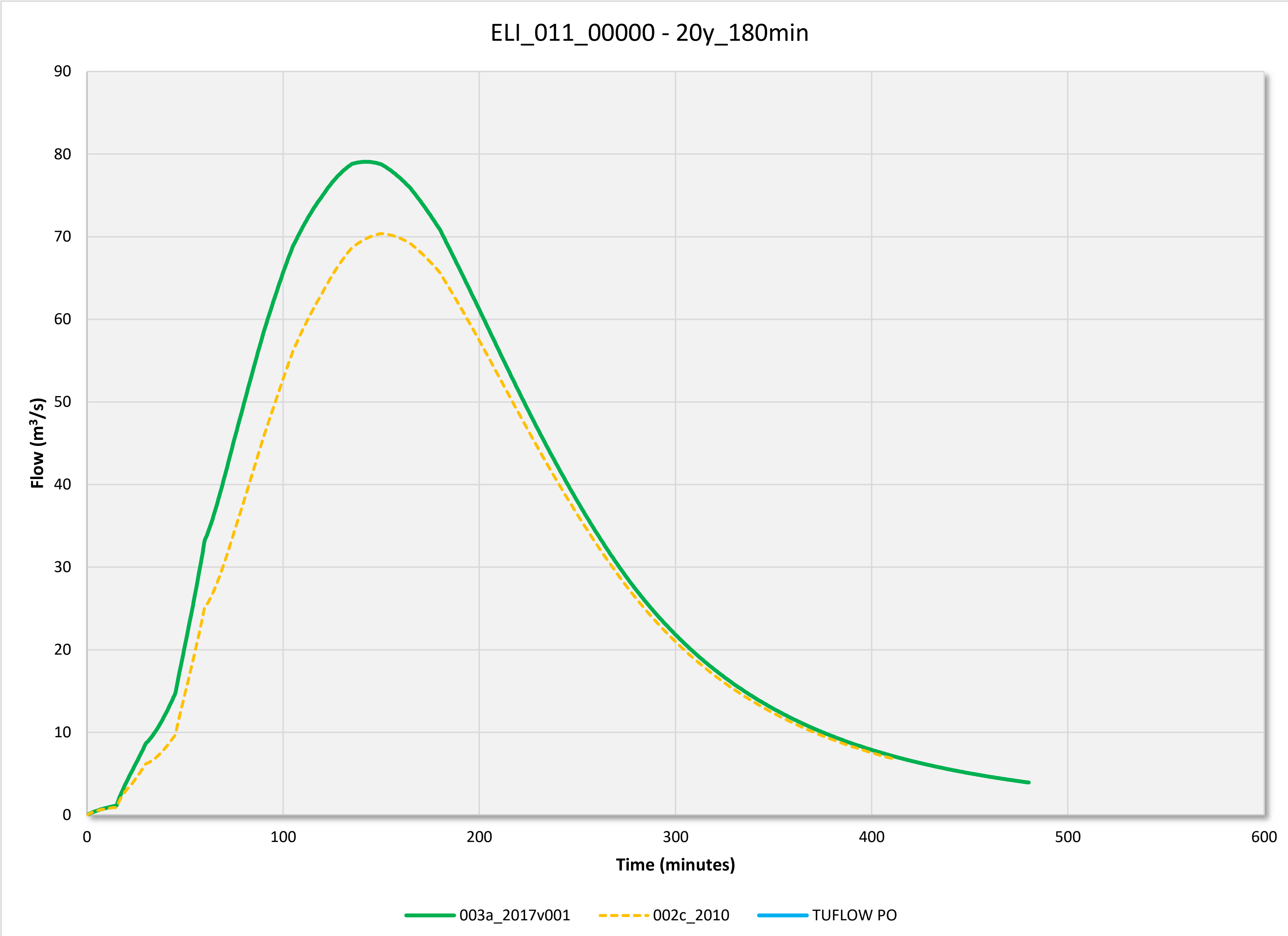
GMC_001_00000 - 100y_180min
Flow (m³/s)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



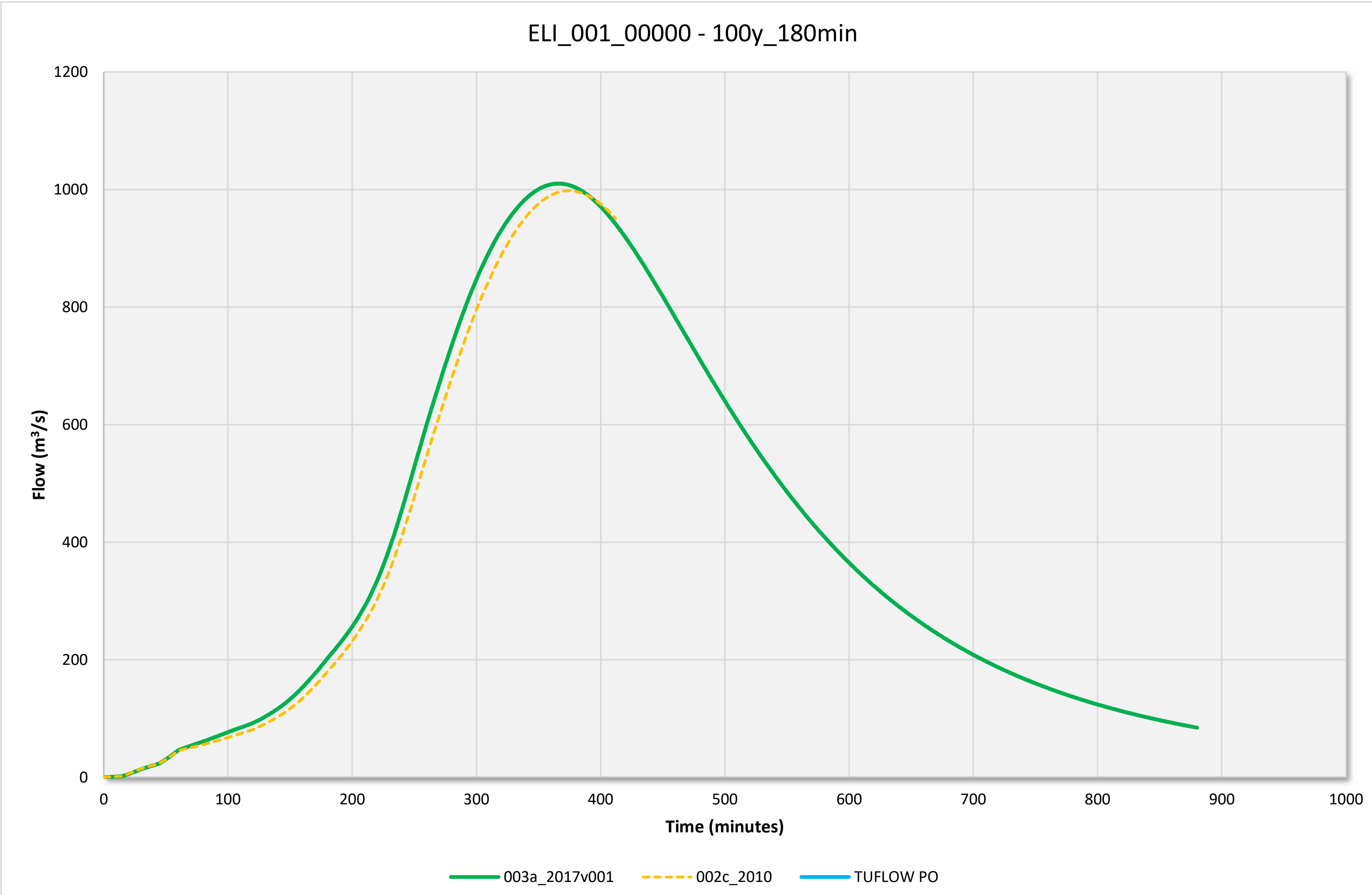
GMC_001_00000 - 20y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
0
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO



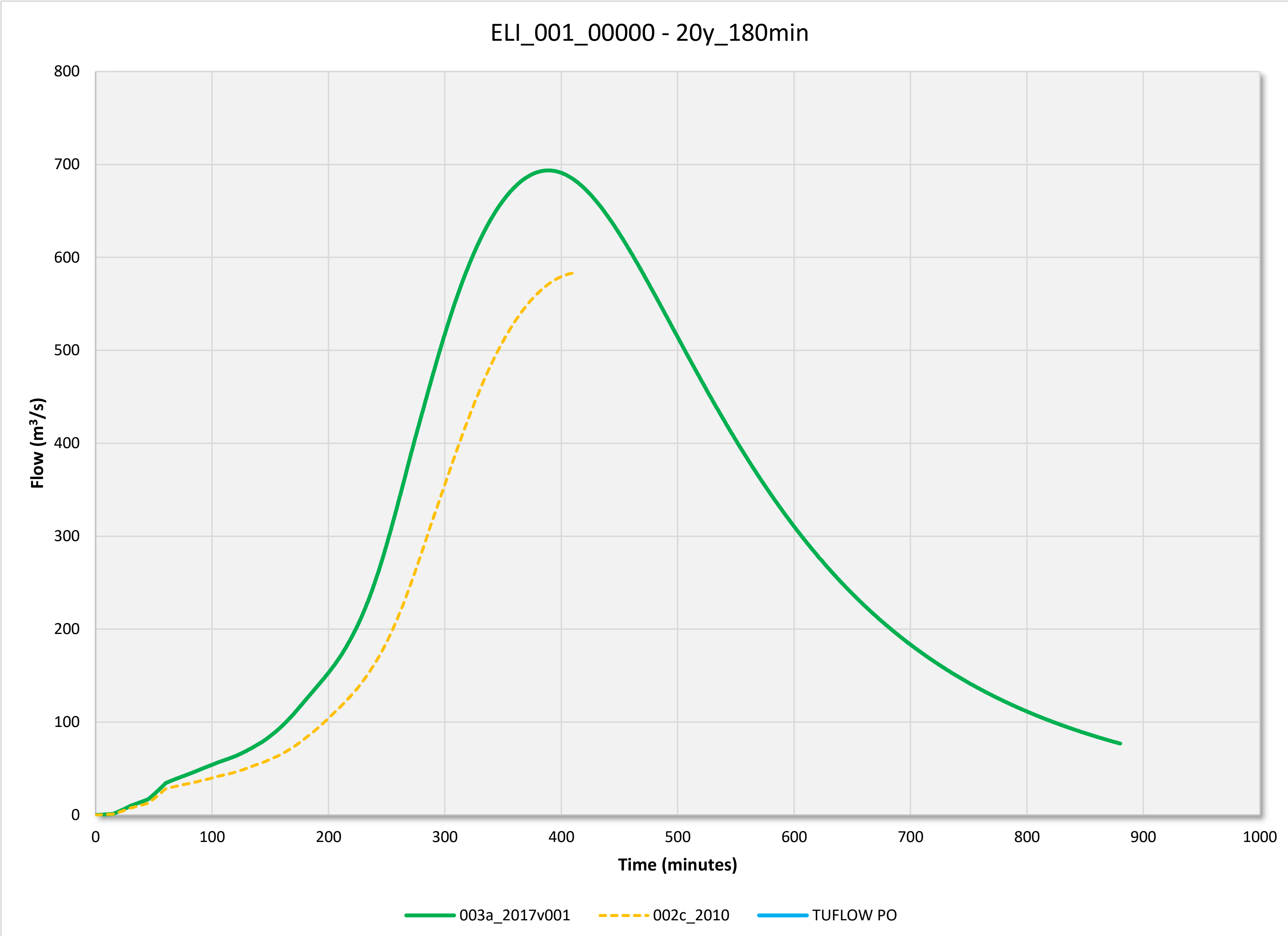
ELI_011_00000 - 100y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
450
500
003a_2017v001
002c_2010
TUFLOW PO

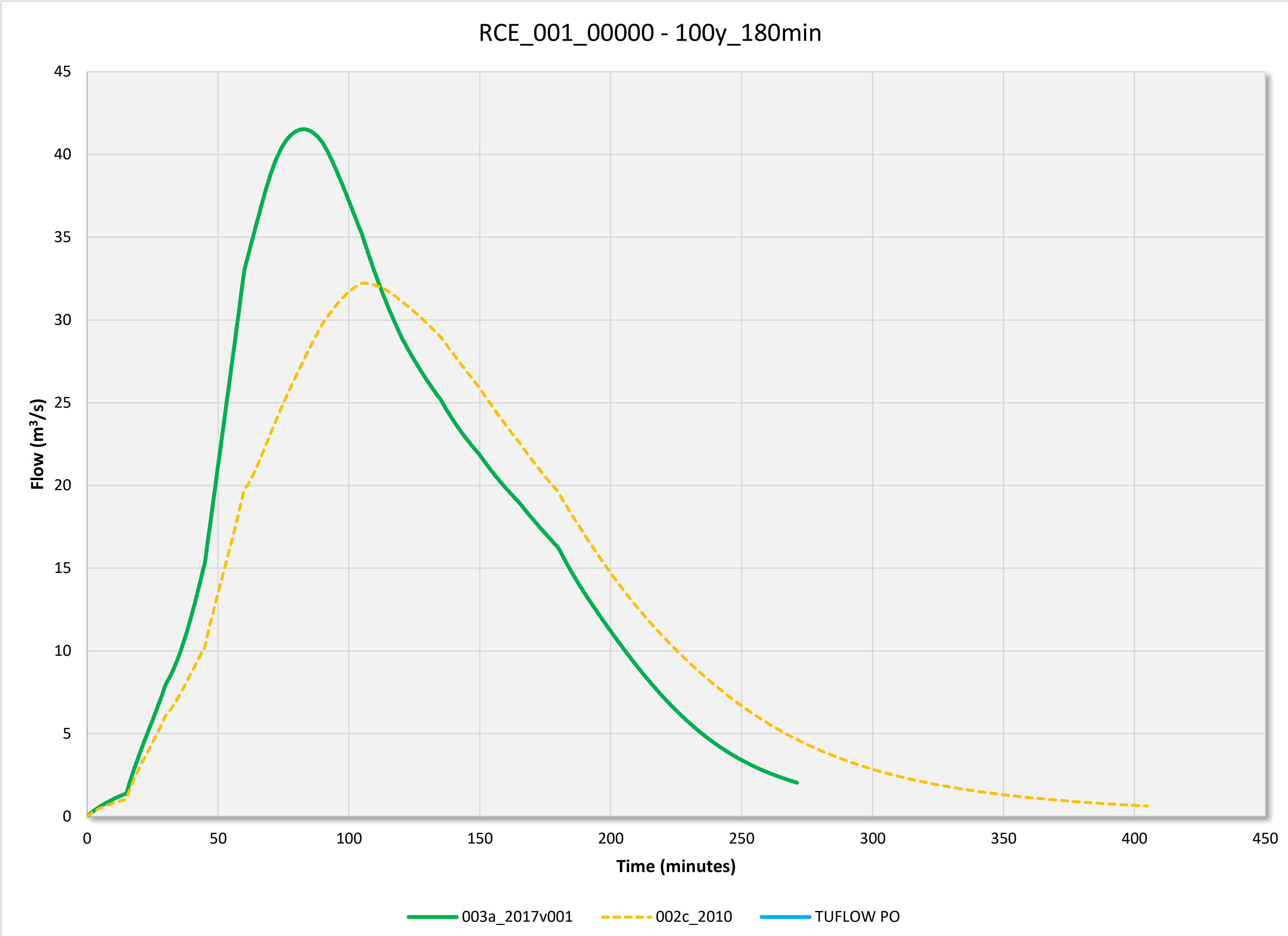


ELI_011_00000 - 20y_180min
Flow (m³/s)
Time (minutes)
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
003a_2017v001
002c_2010
TUFLOW PO

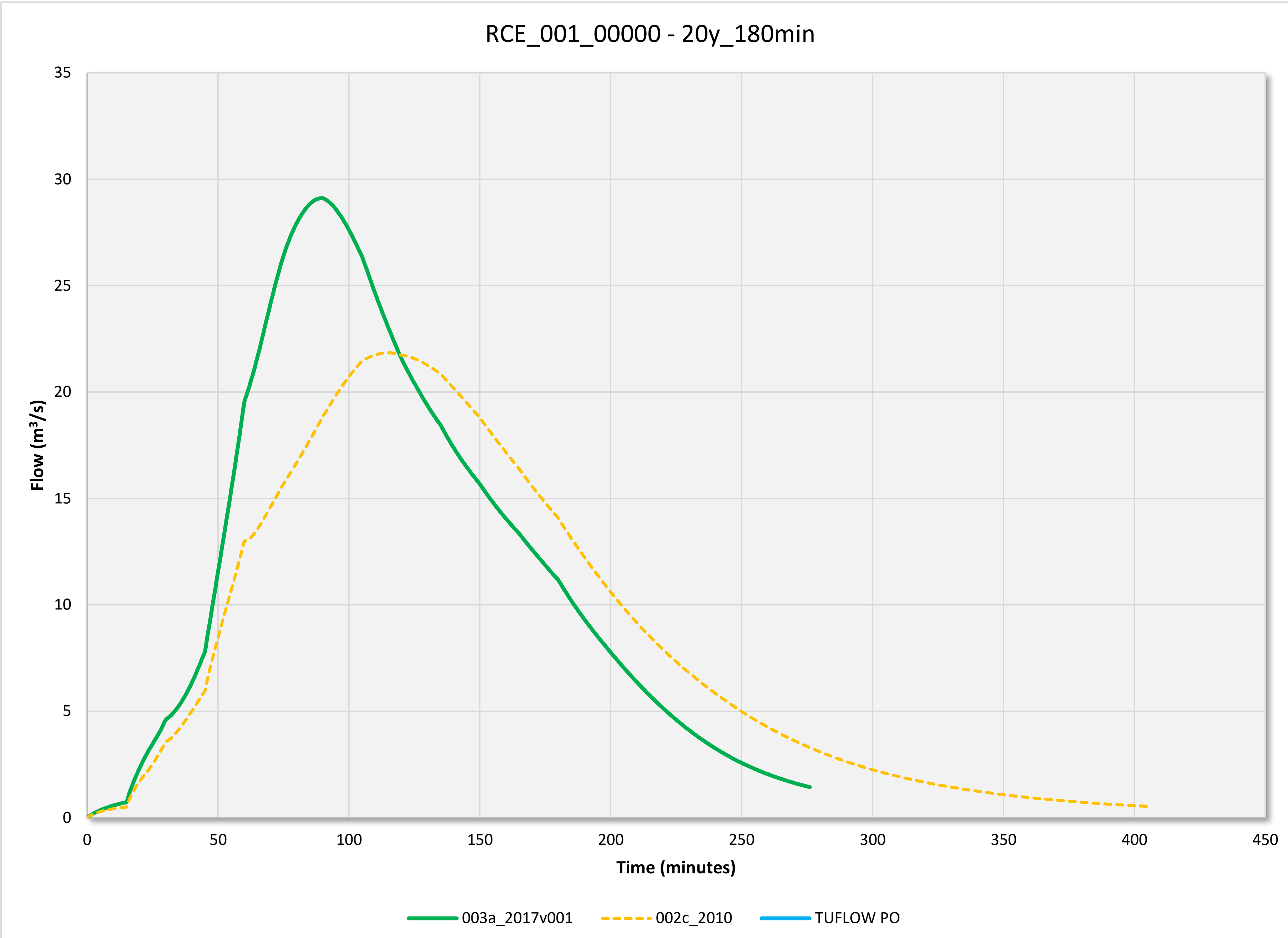


ELI_001_00000 - 100y_180min
Flow (m³/s)
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

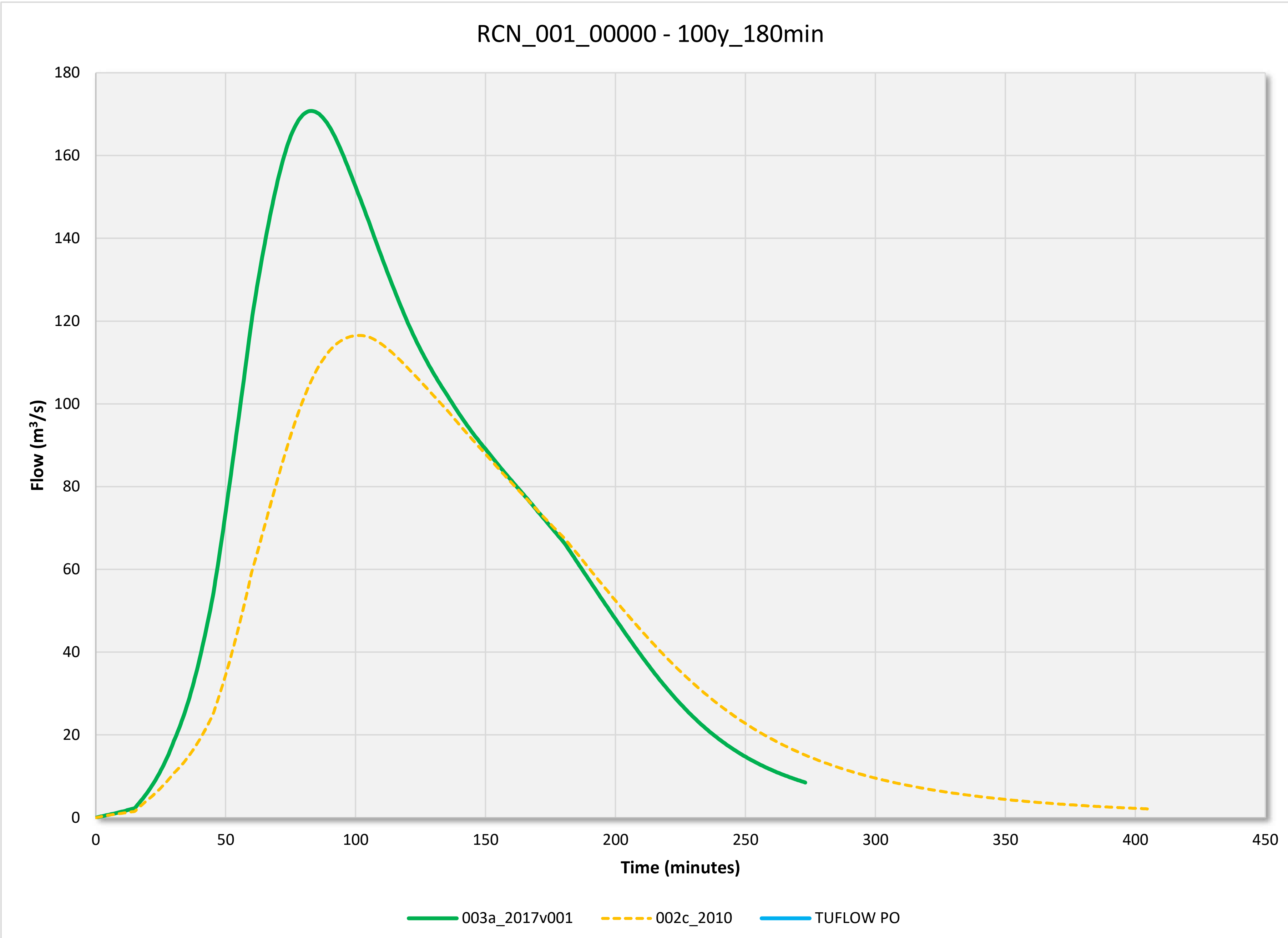

ELI_001_00000 - 20y_180min
Flow (m³/s)
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



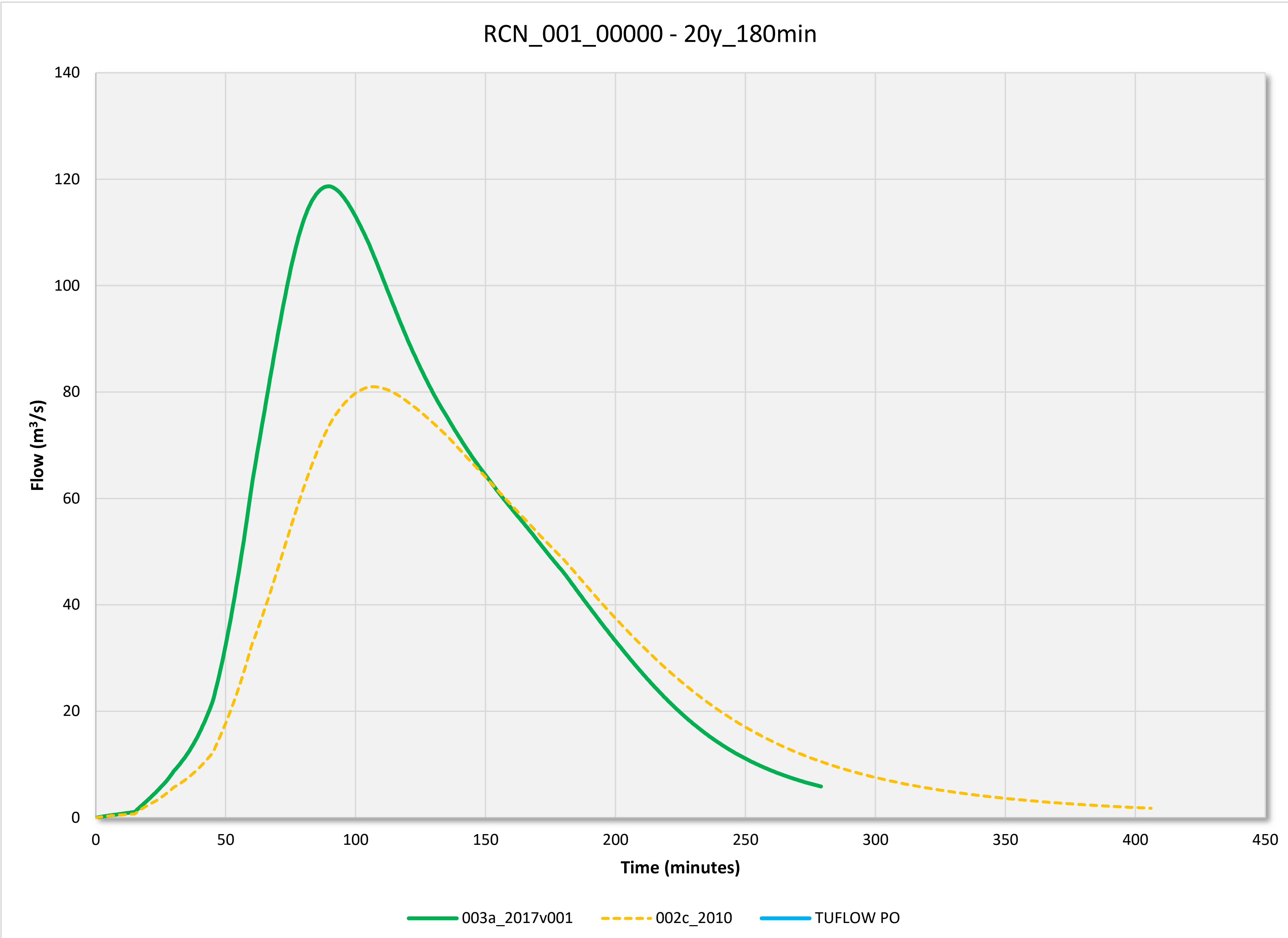
RCE_001_00000 - 100y_180min
Flow (m³/s)
Time (minutes)
0
5
10
15
20
25
30
35
40
45
0
50
100
150
200
250
300
350
400
450
003a_2017v001
002c_2010
TUFLOW PO



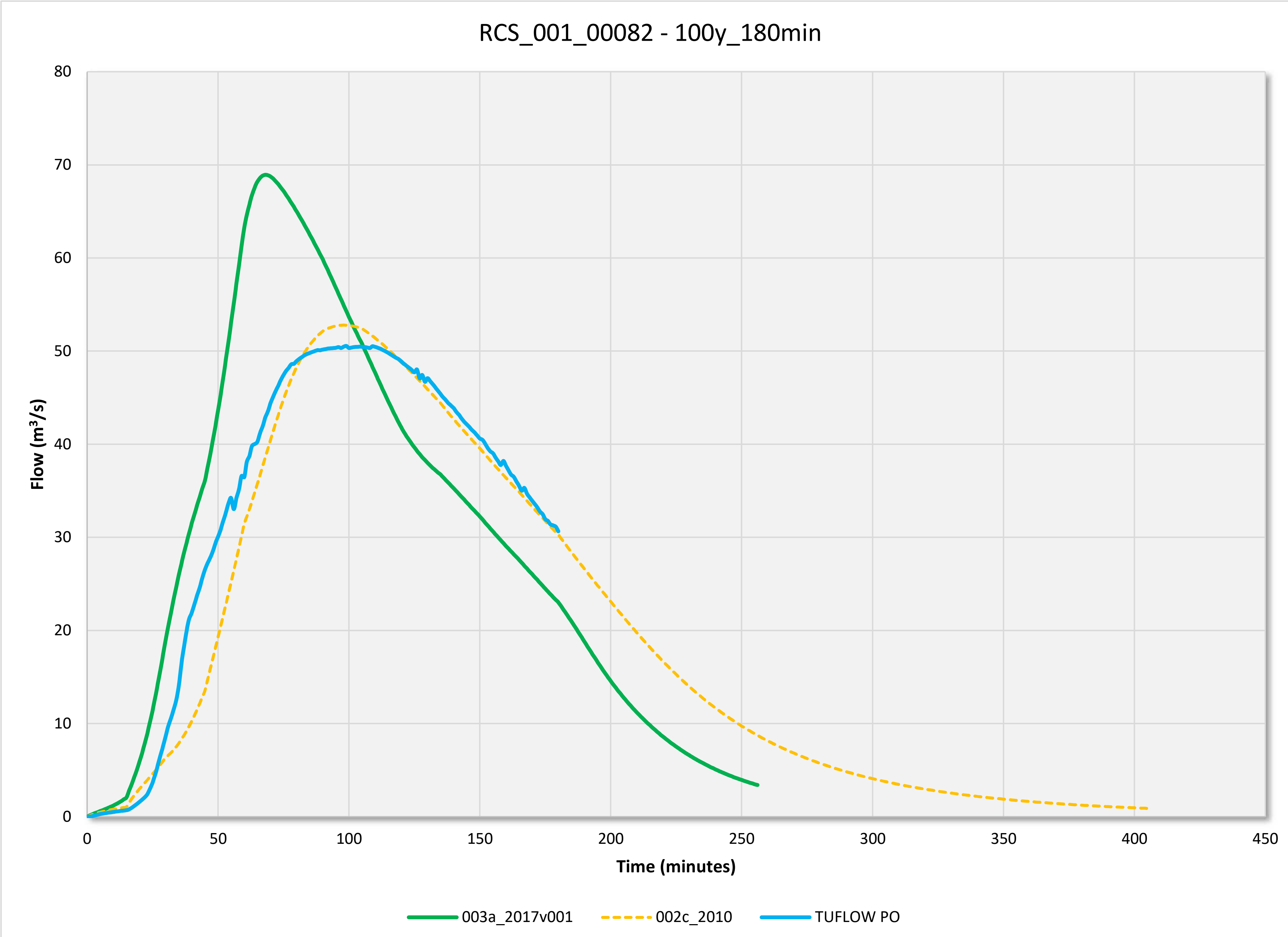
RCE_001_00000 - 20y_180min
Flow (m³/s)
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

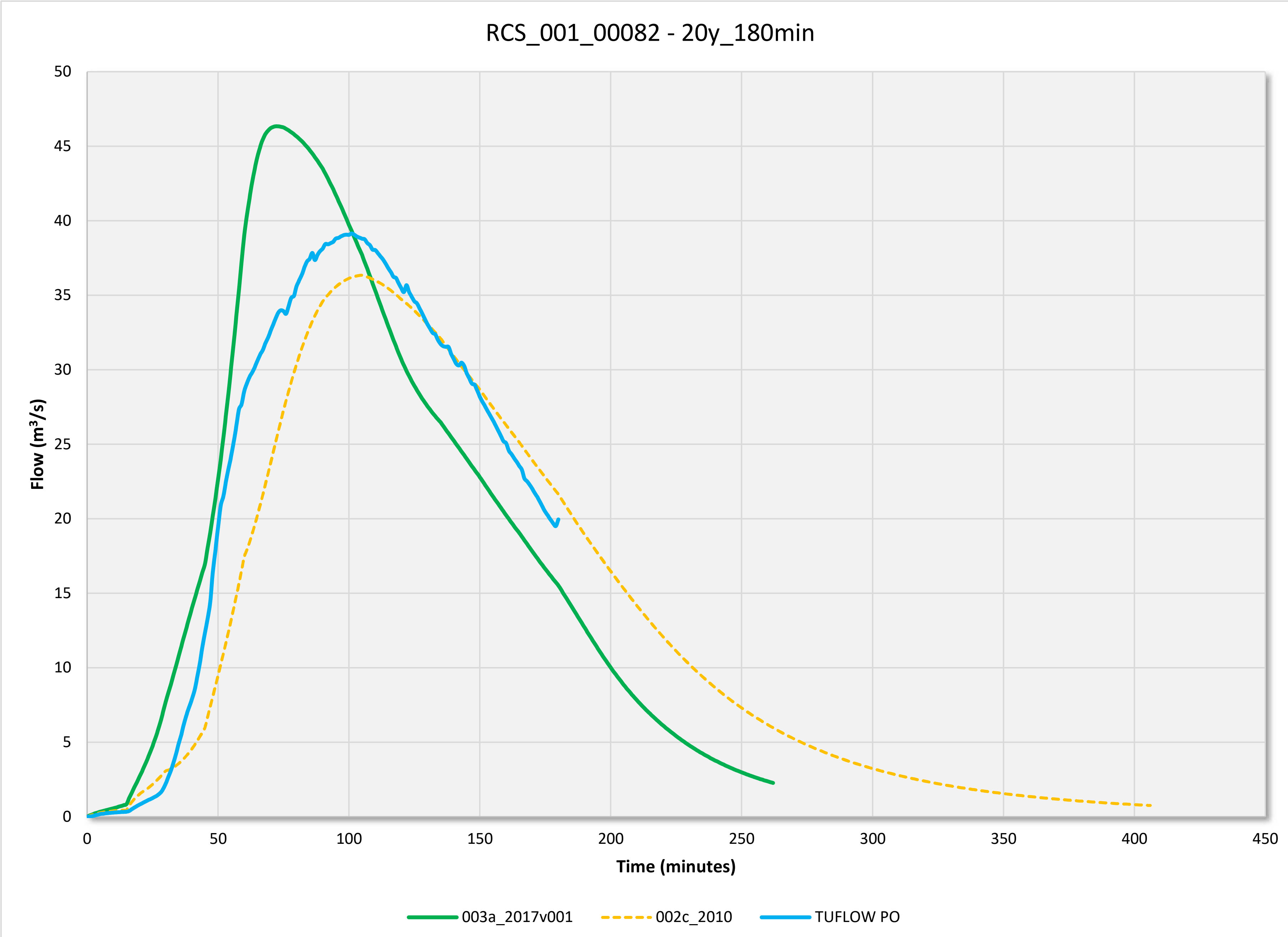


RCN_001_00000 - 100y_180min
Flow (m³/s)
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

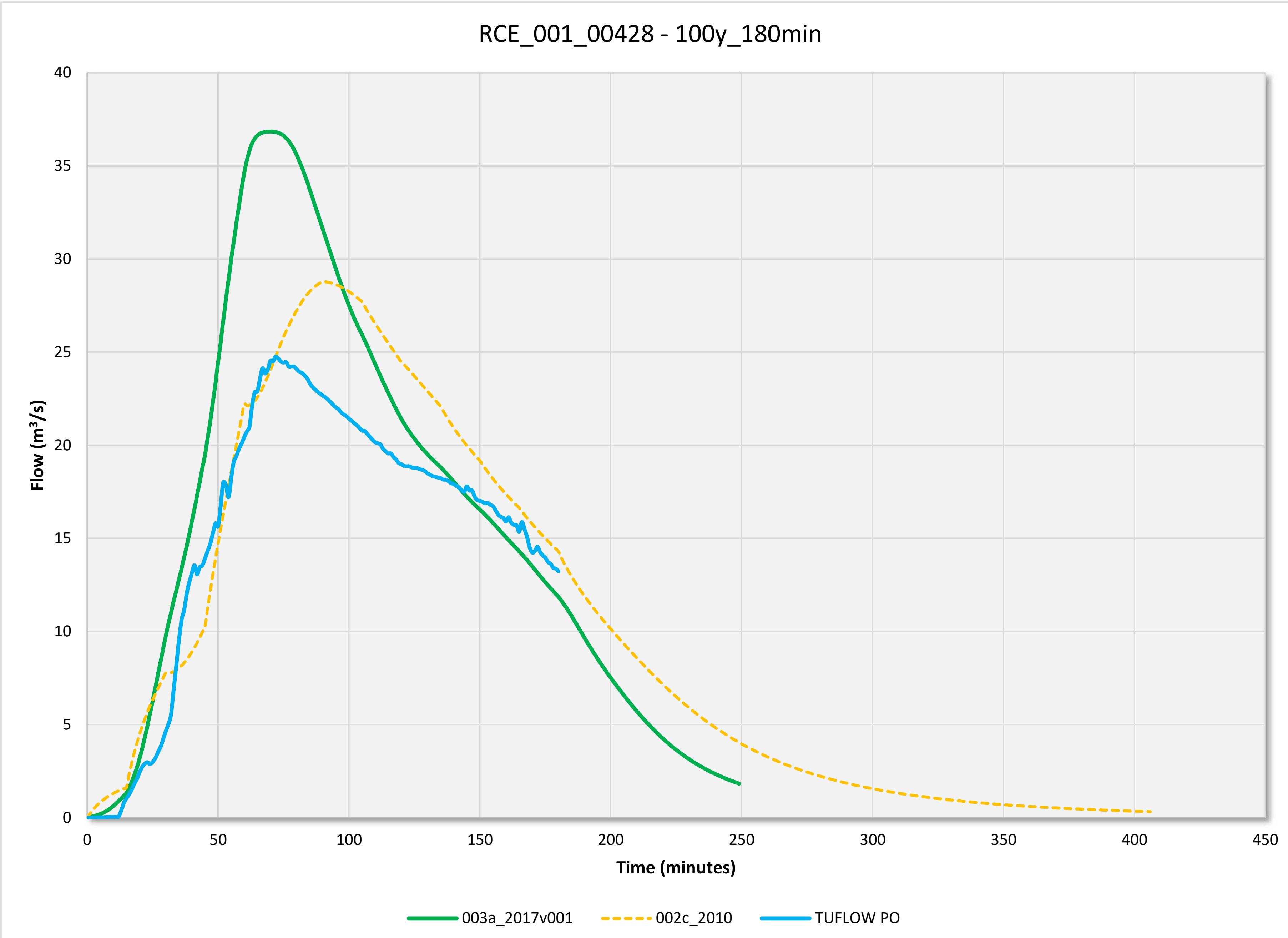


RCN_001_00000 - 20y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400
450
003a_2017v001
002c_2010
TUFLOW PO

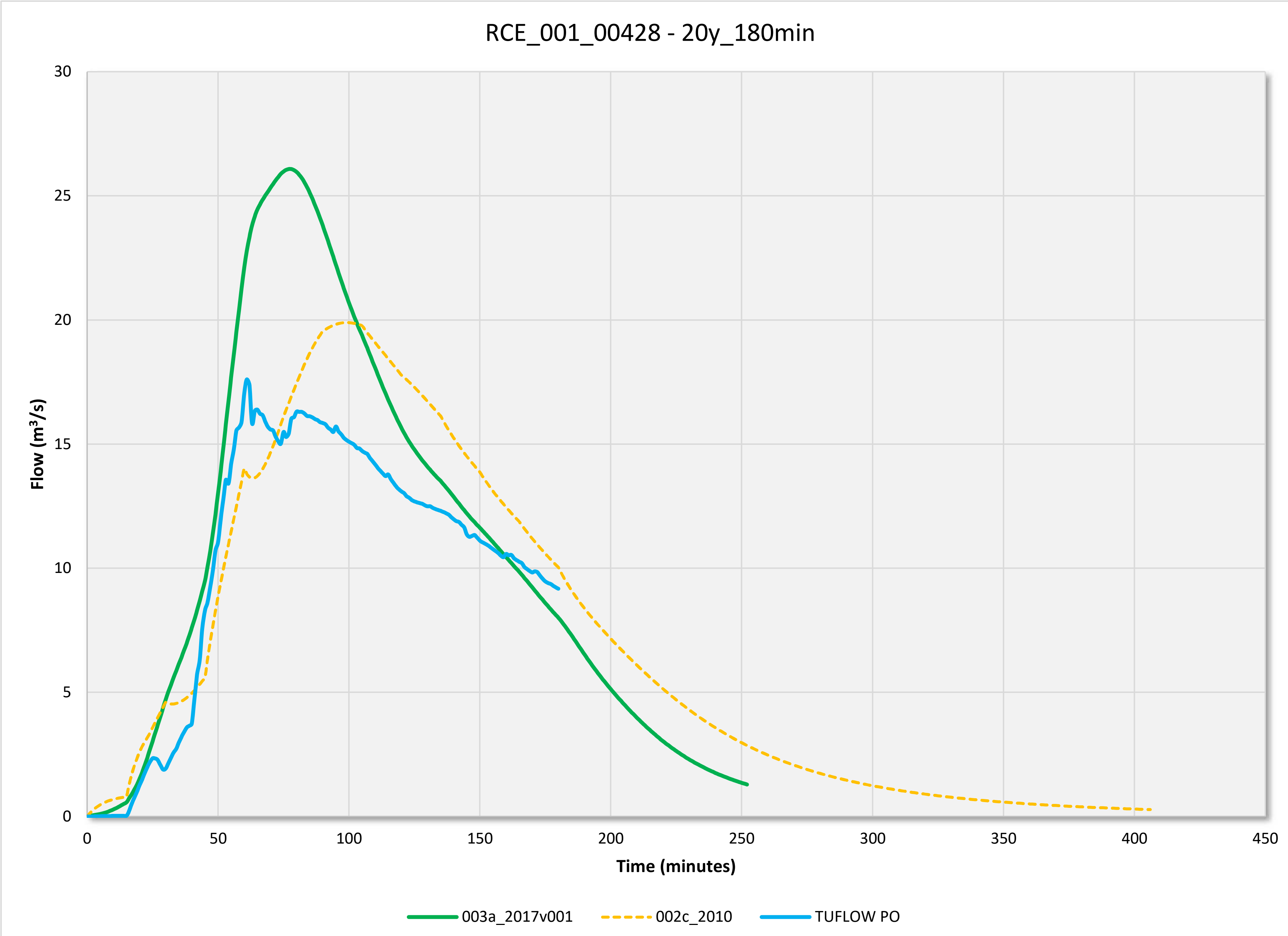

RCS_001_00082 - 100y_180min
Flow (m³/s)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

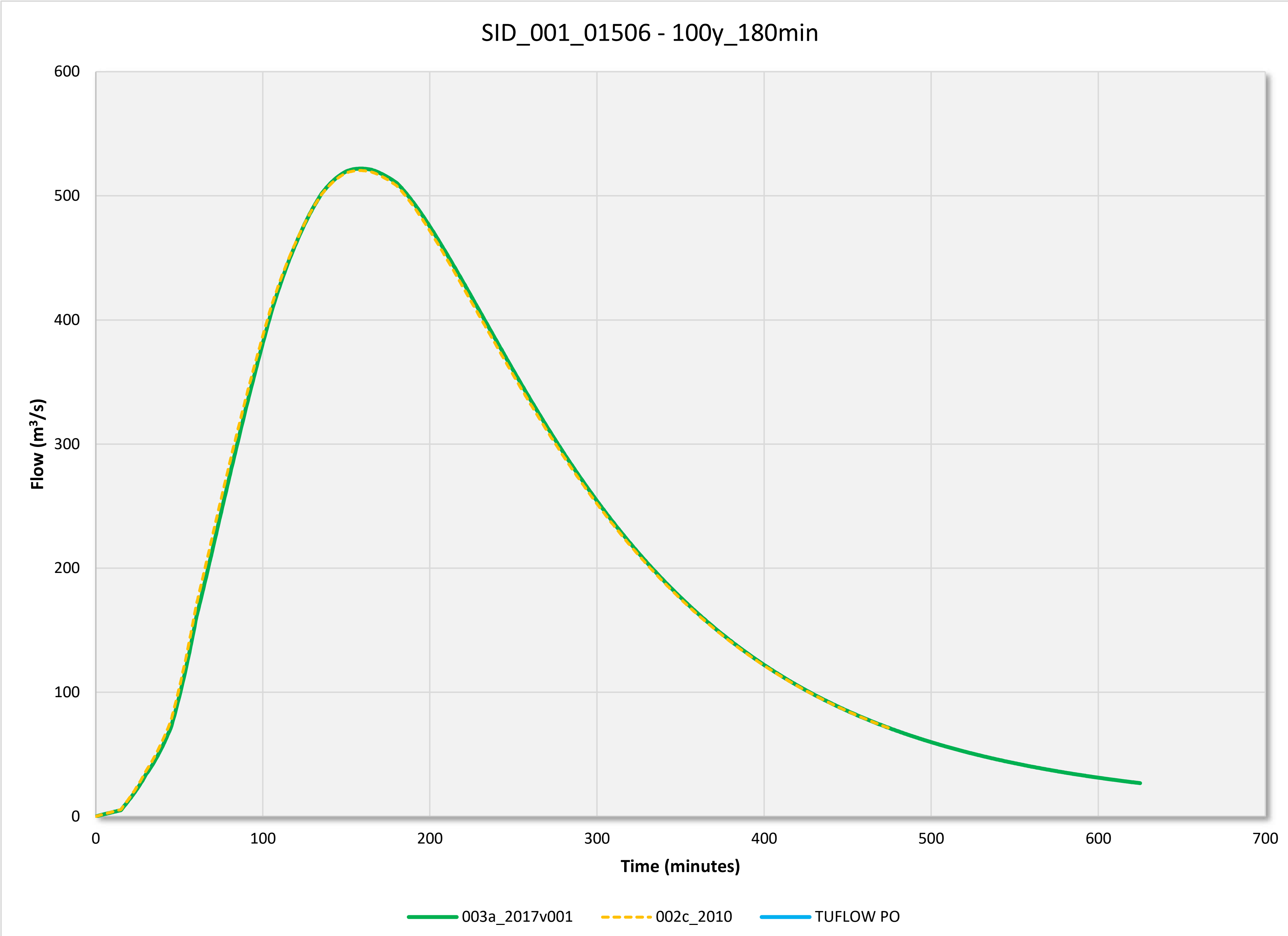


RCS_001_00082 - 20y_180min
Flow (m³/s)
Time (minutes)
0
5
10
15
20
25
30
35
40
45
50
0
50
100
150
200
250
300
350
400
450
003a_2017v001
002c_2010
TUFLOW PO

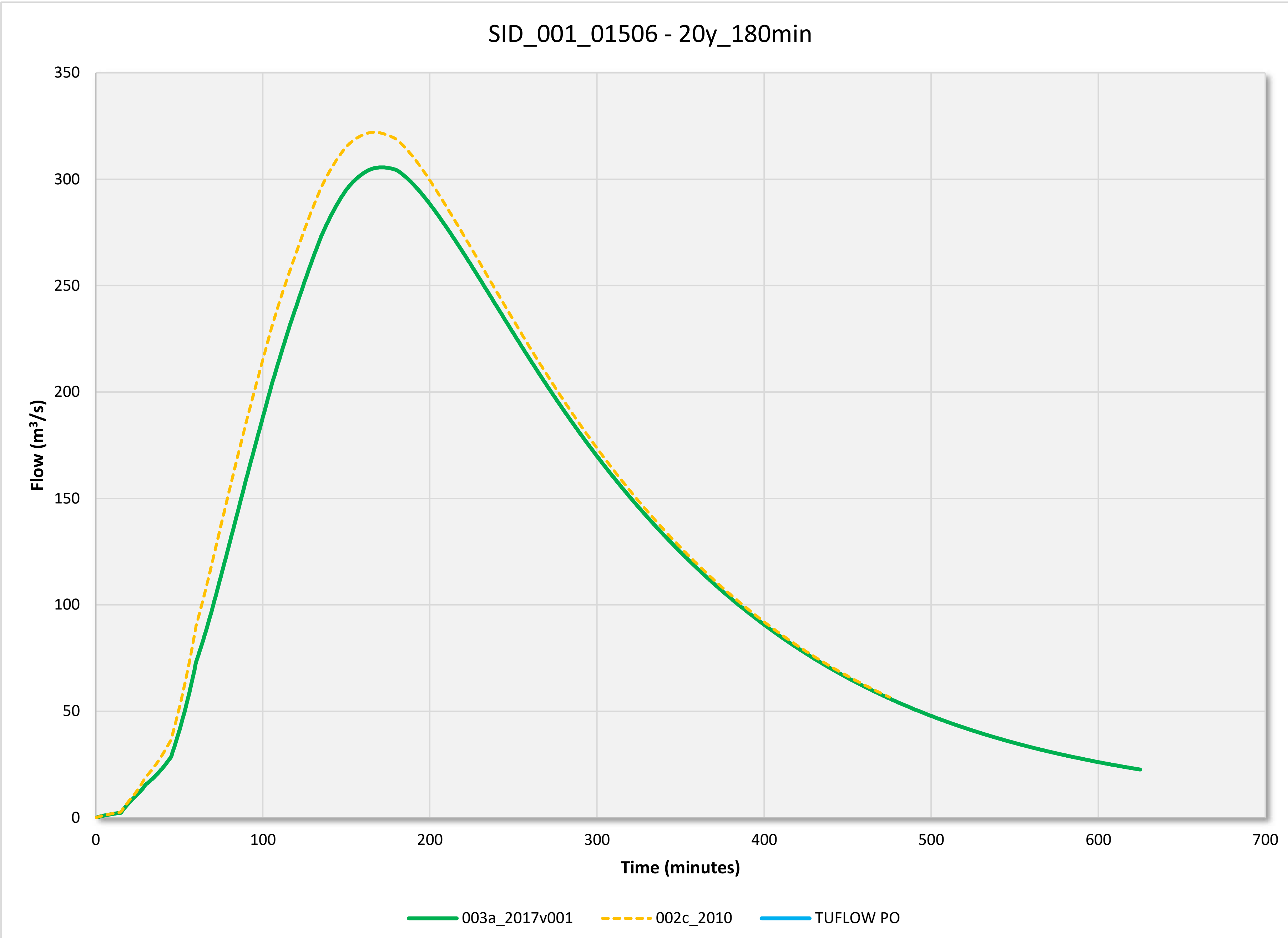


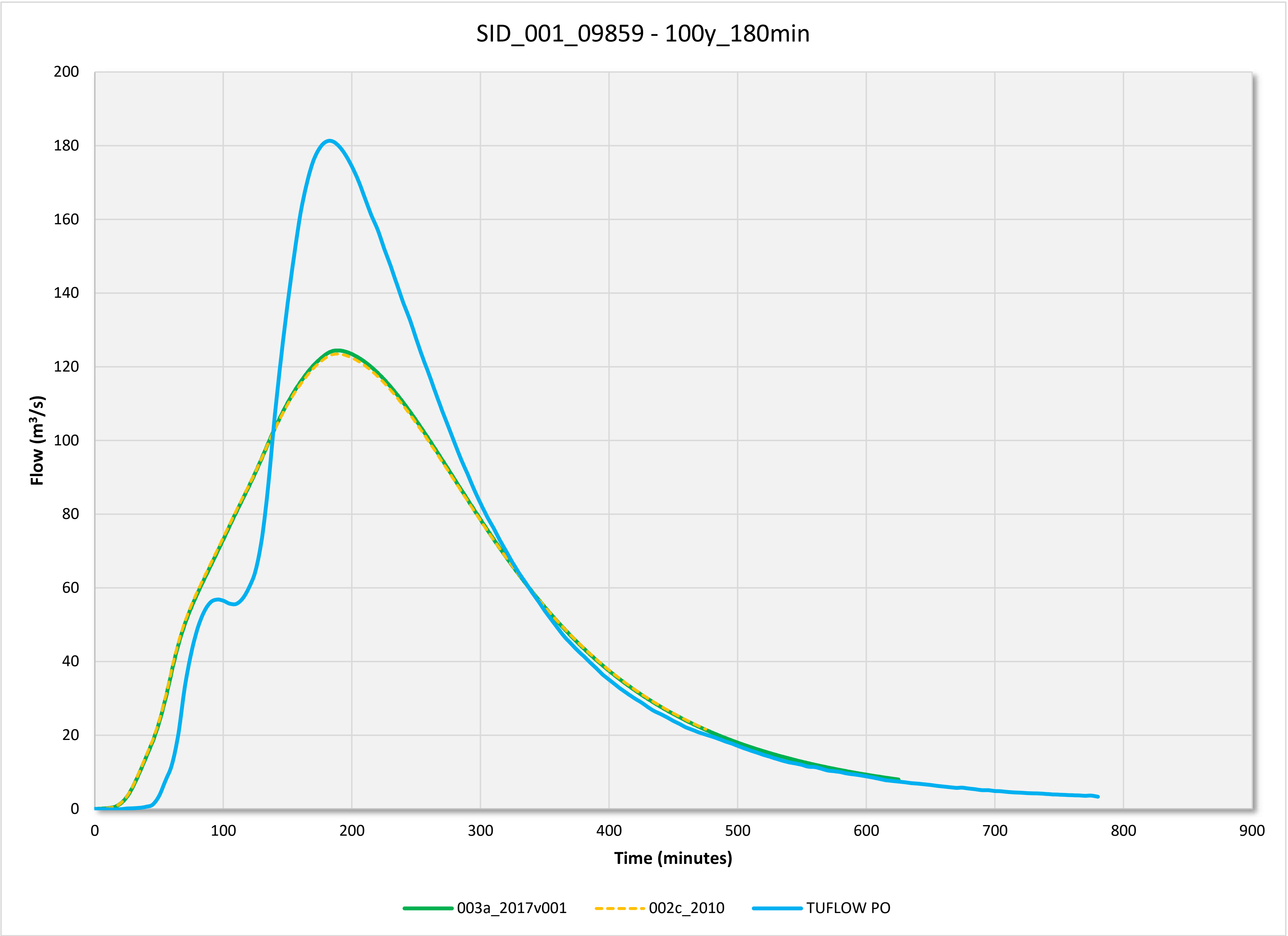
RCE_001_00428 - 100y_180min
Flow (m³/s)
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

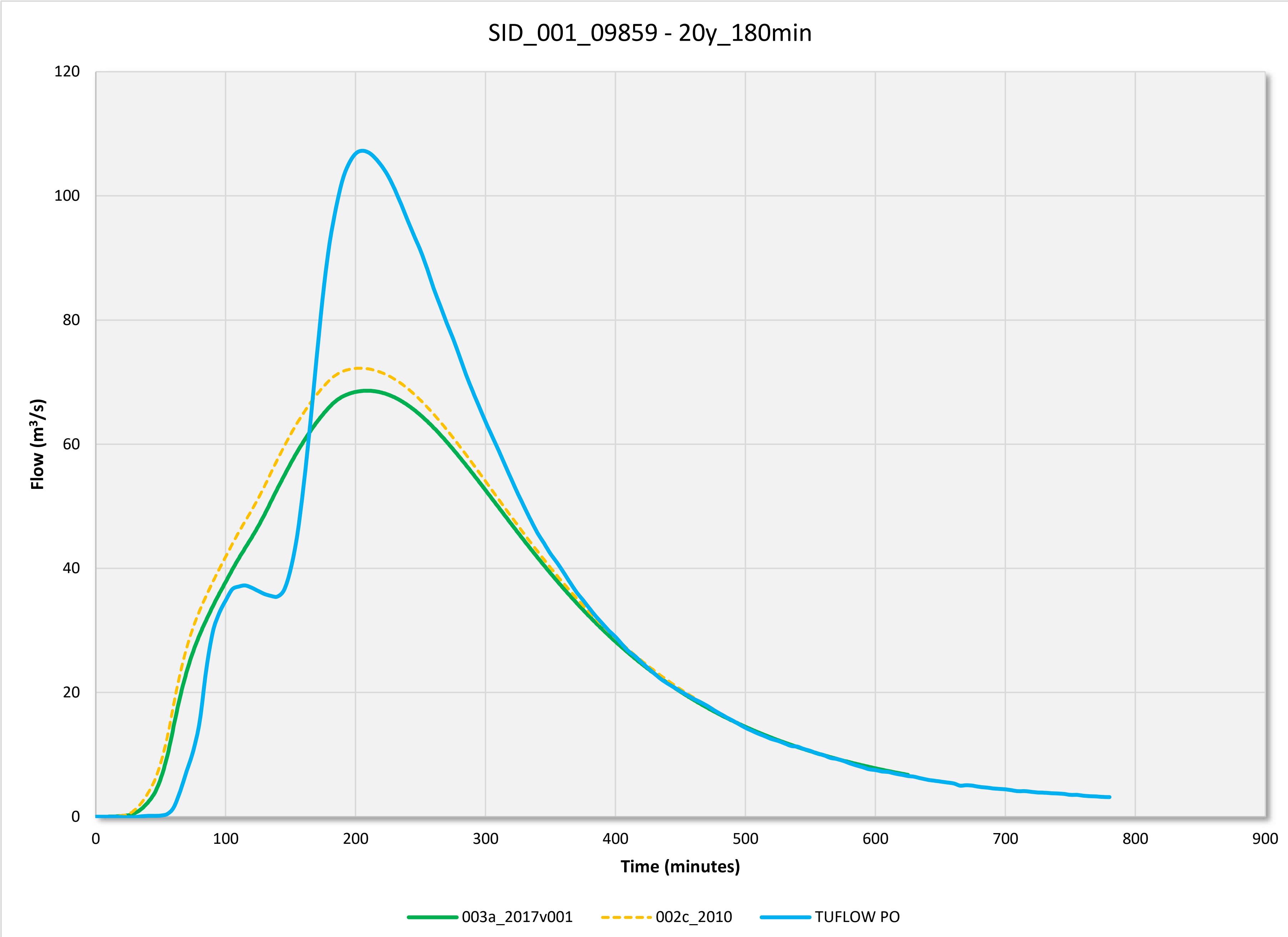

RCE_001_00428 - 20y_180min
Flow (m³/s)
Time (minutes)
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400
450
003a_2017v001
002c_2010
TUFLOW PO

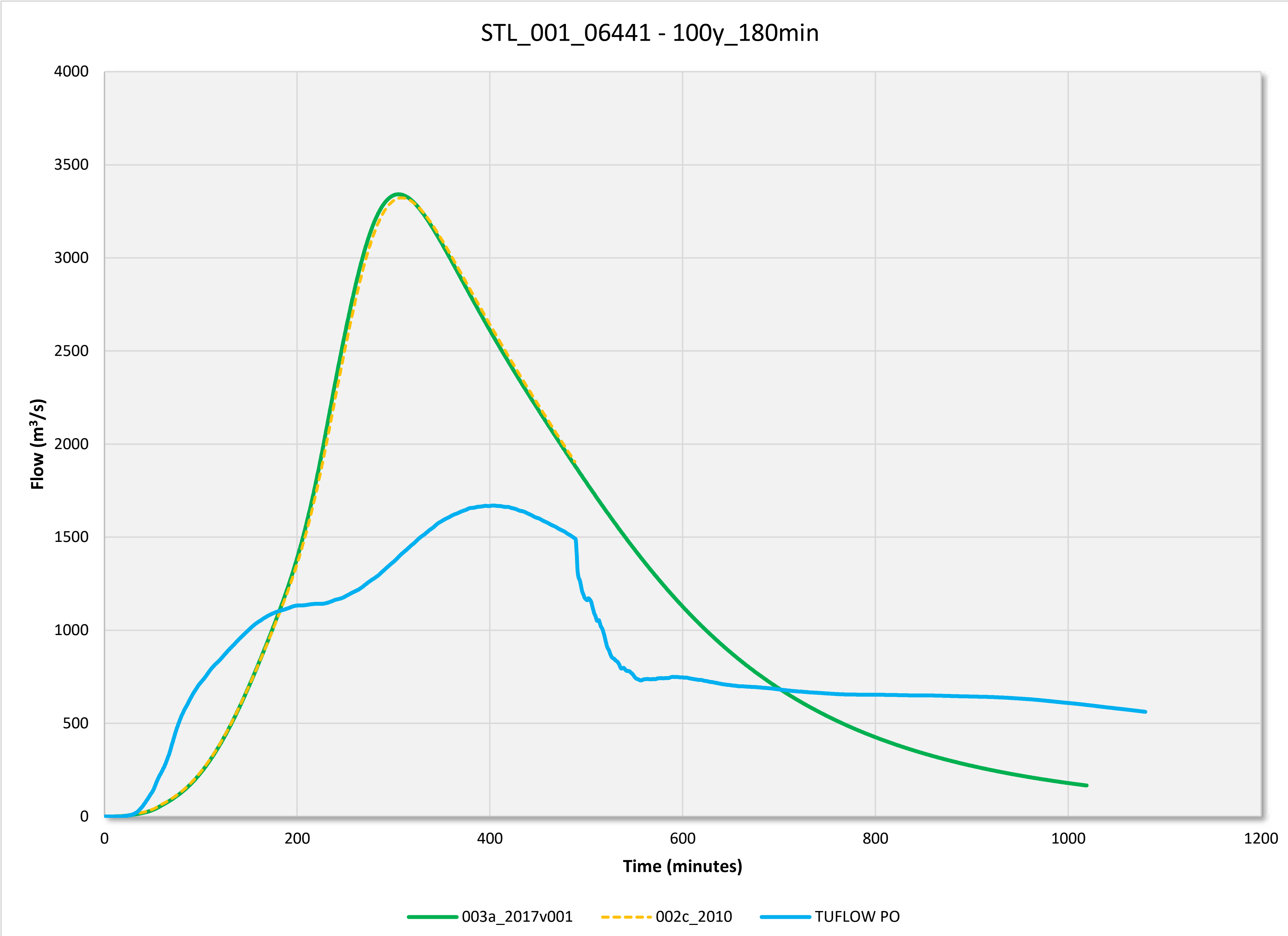


SID_001_01506 - 100y_180min
Flow (m³/s)
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

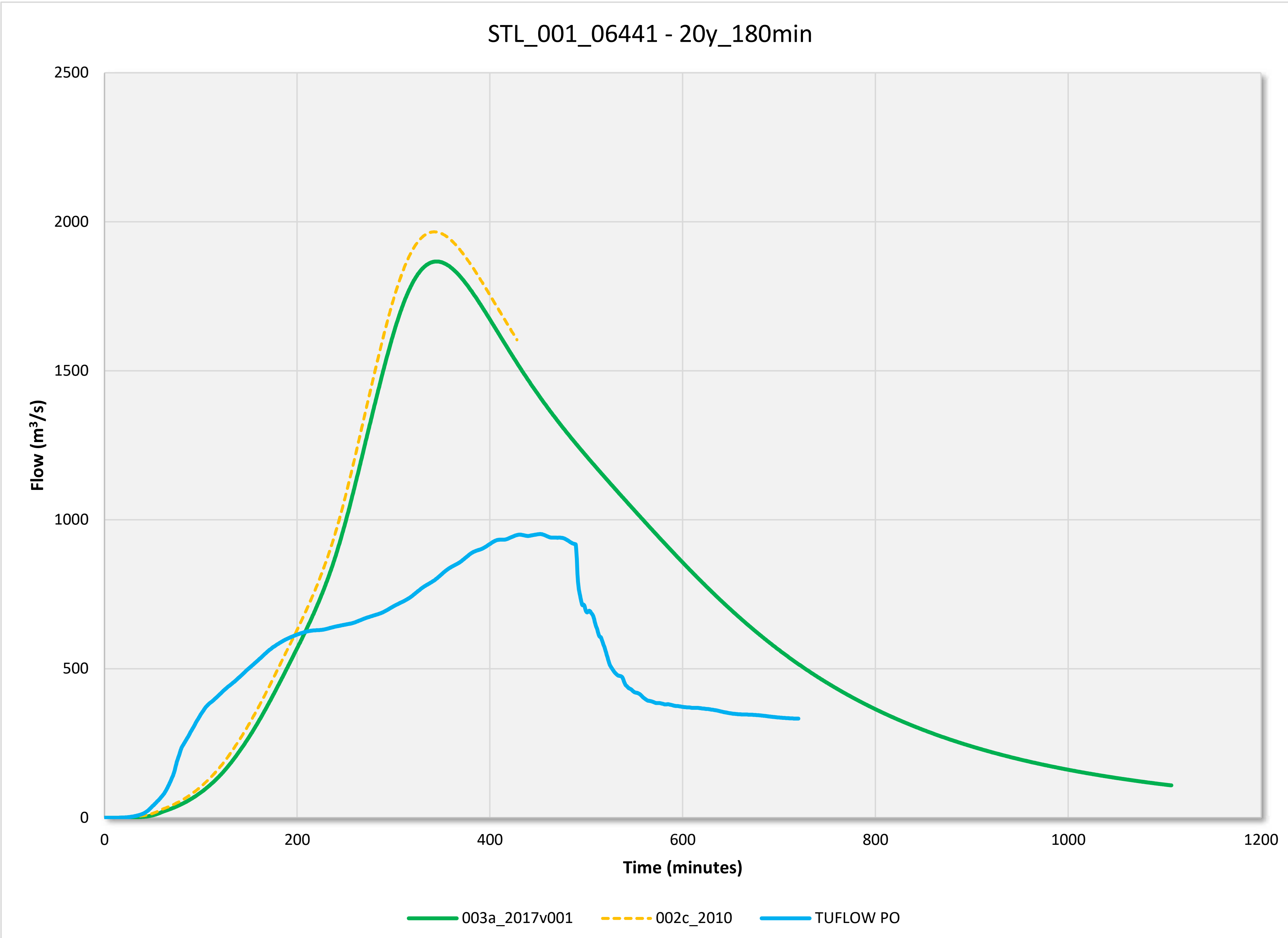

SID_001_01506 - 20y_180min
Flow (m³/s)
0
50
100
150
200
250
300
350
0
100
200
300
400
500
600
700
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


SID_001_09859 - 100y_180min
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

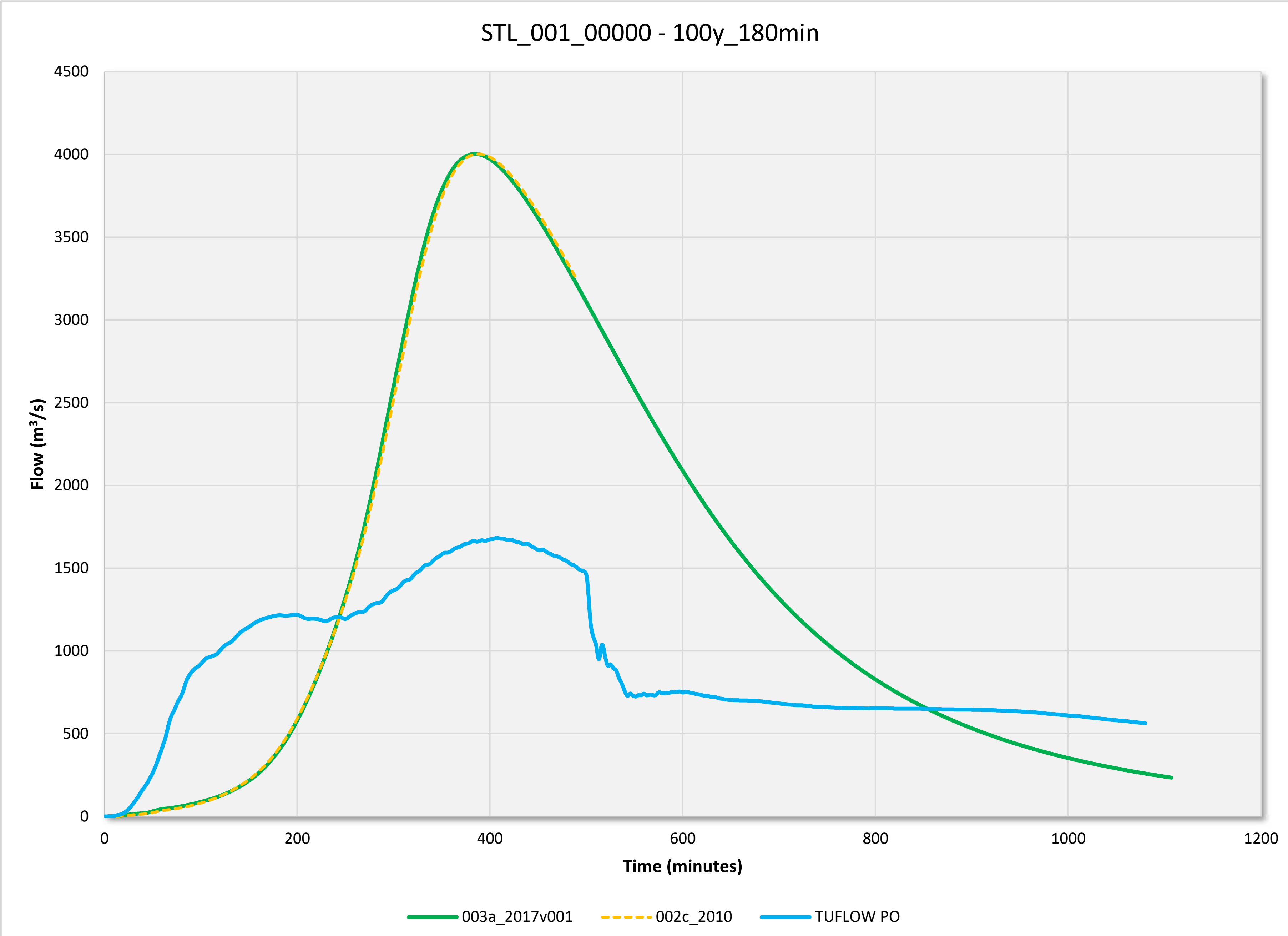

SID_001_09859 - 20y_180min
Flow (m³/s)
Time (minutes)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO



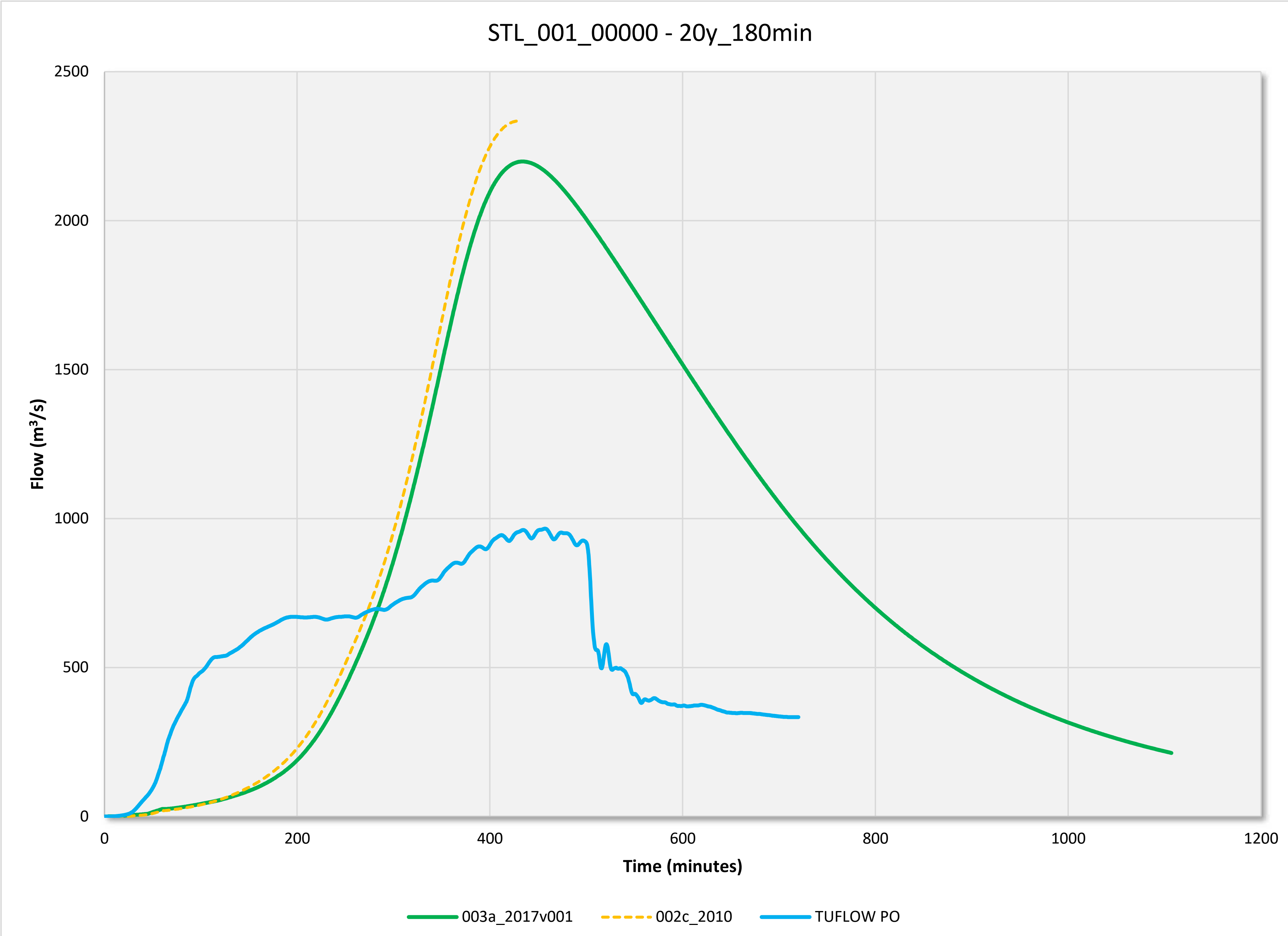
STL_001_06441 - 100y_180min
4000
3500
3000
2500
2000
1500
1000
500
0
Flow (m³/s)
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

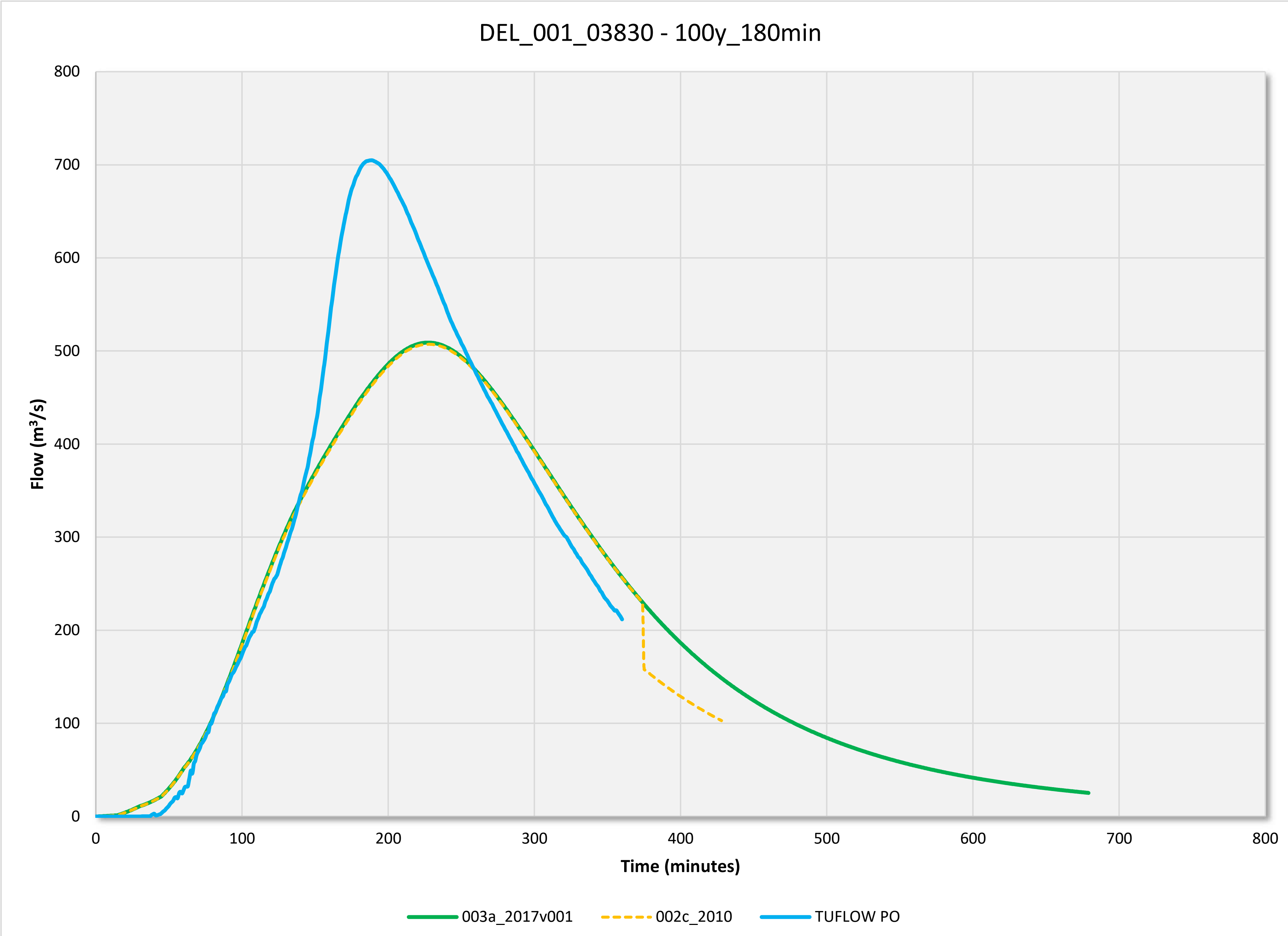


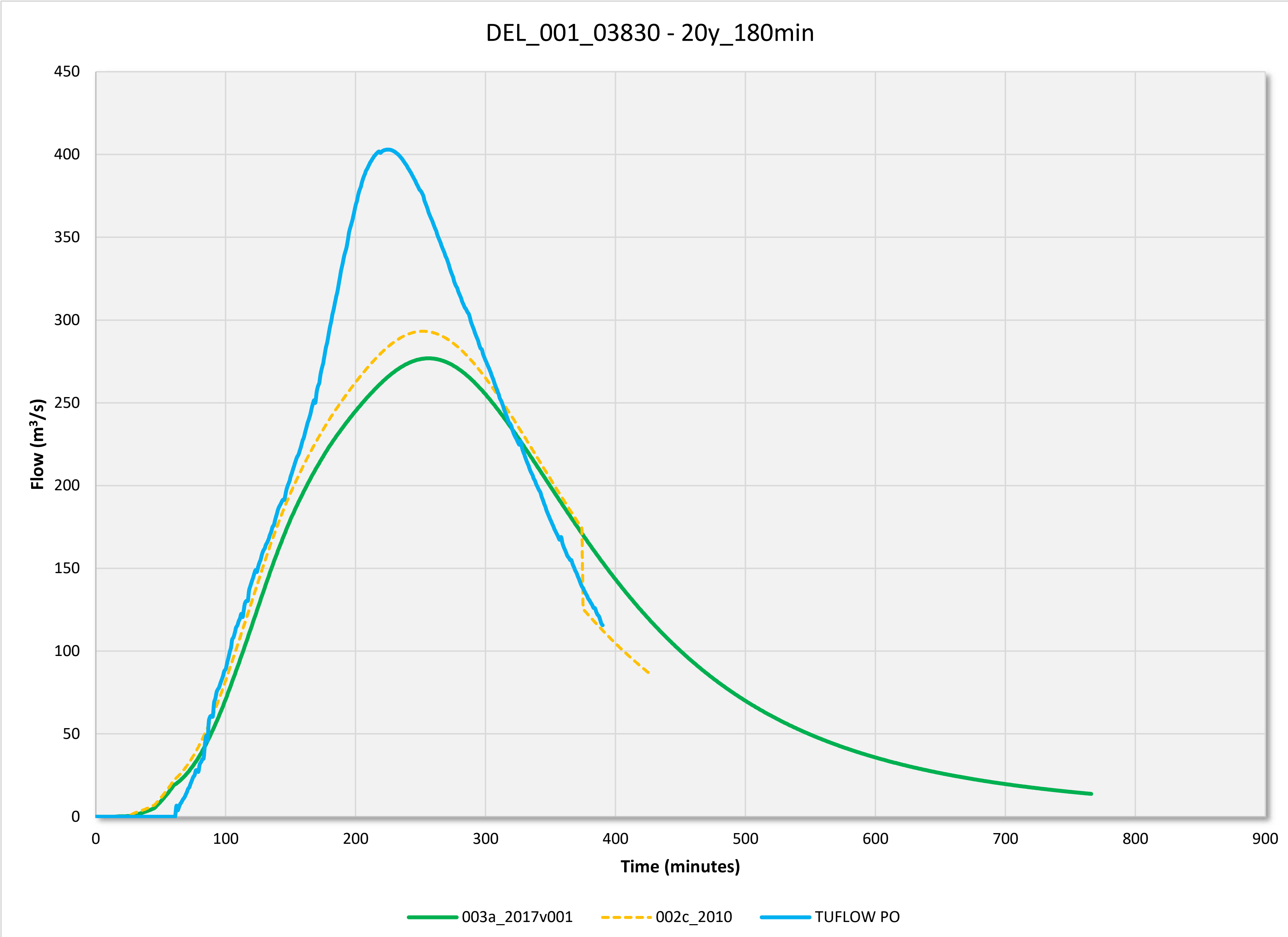
STL_001_06441 - 20y_180min
Flow (m³/s)
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



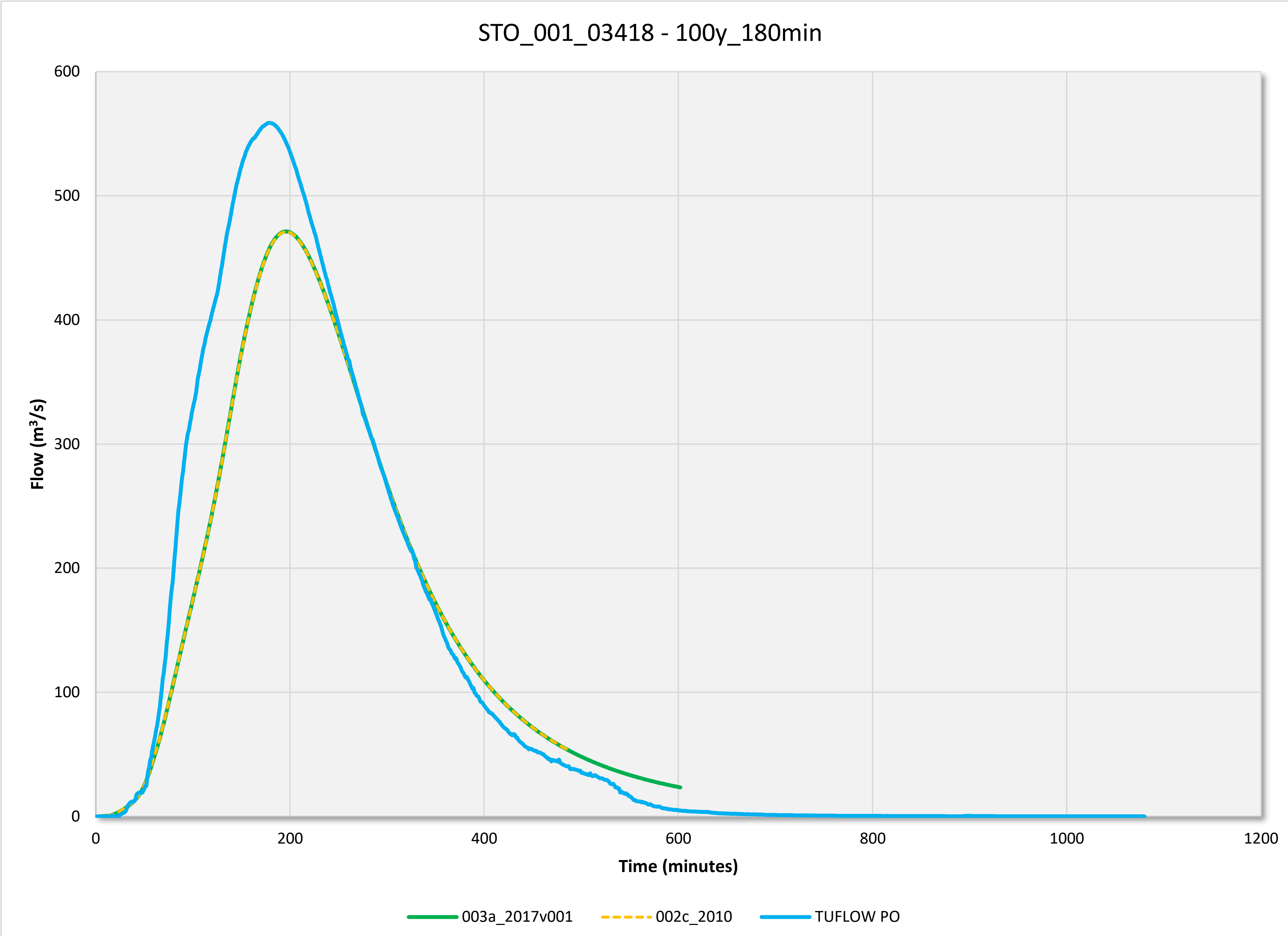
STL_001_00000 - 100y_180min
Flow (m³/s)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

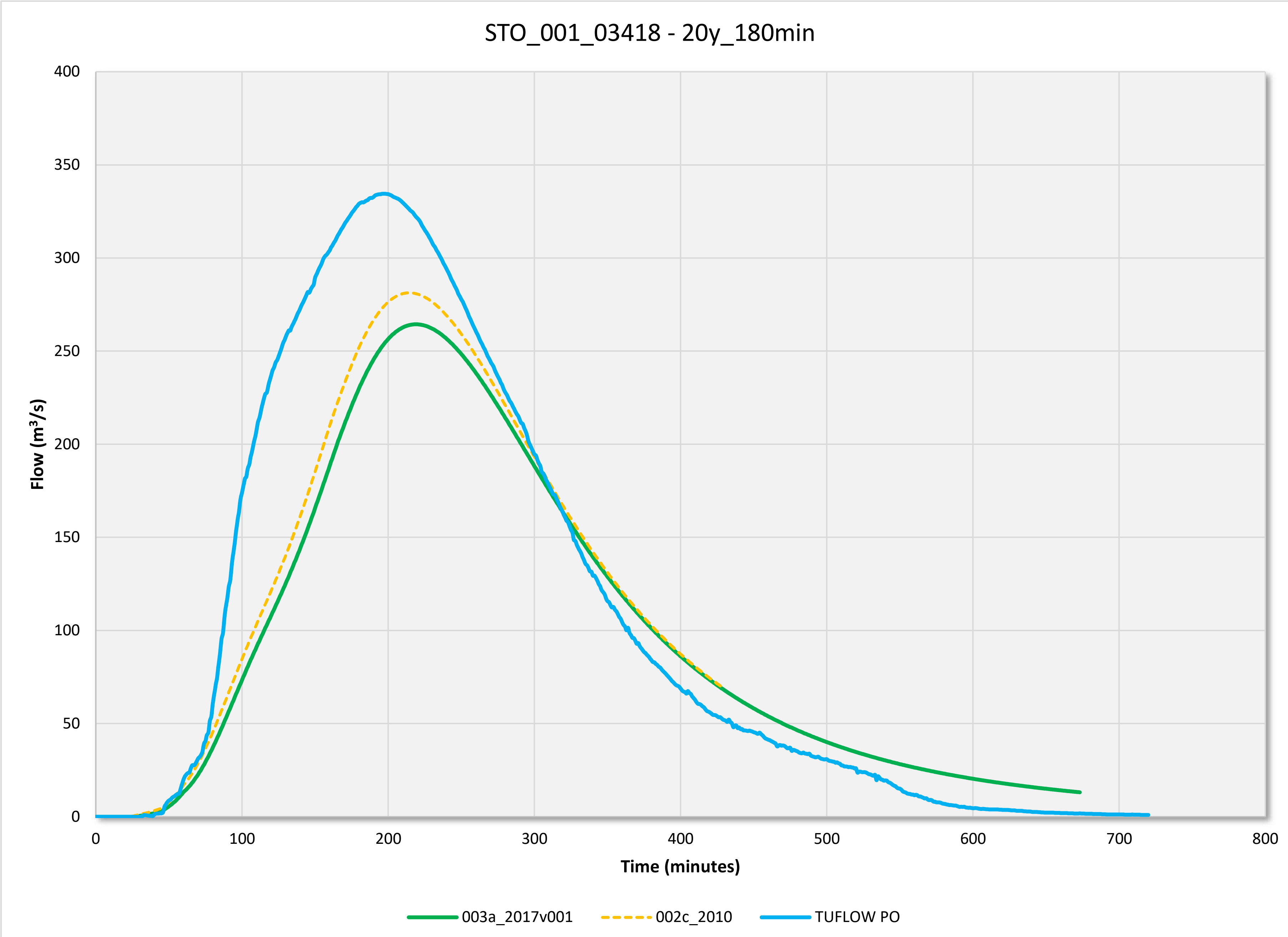

STL_001_00000 - 20y_180min
Flow (m³/s)
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

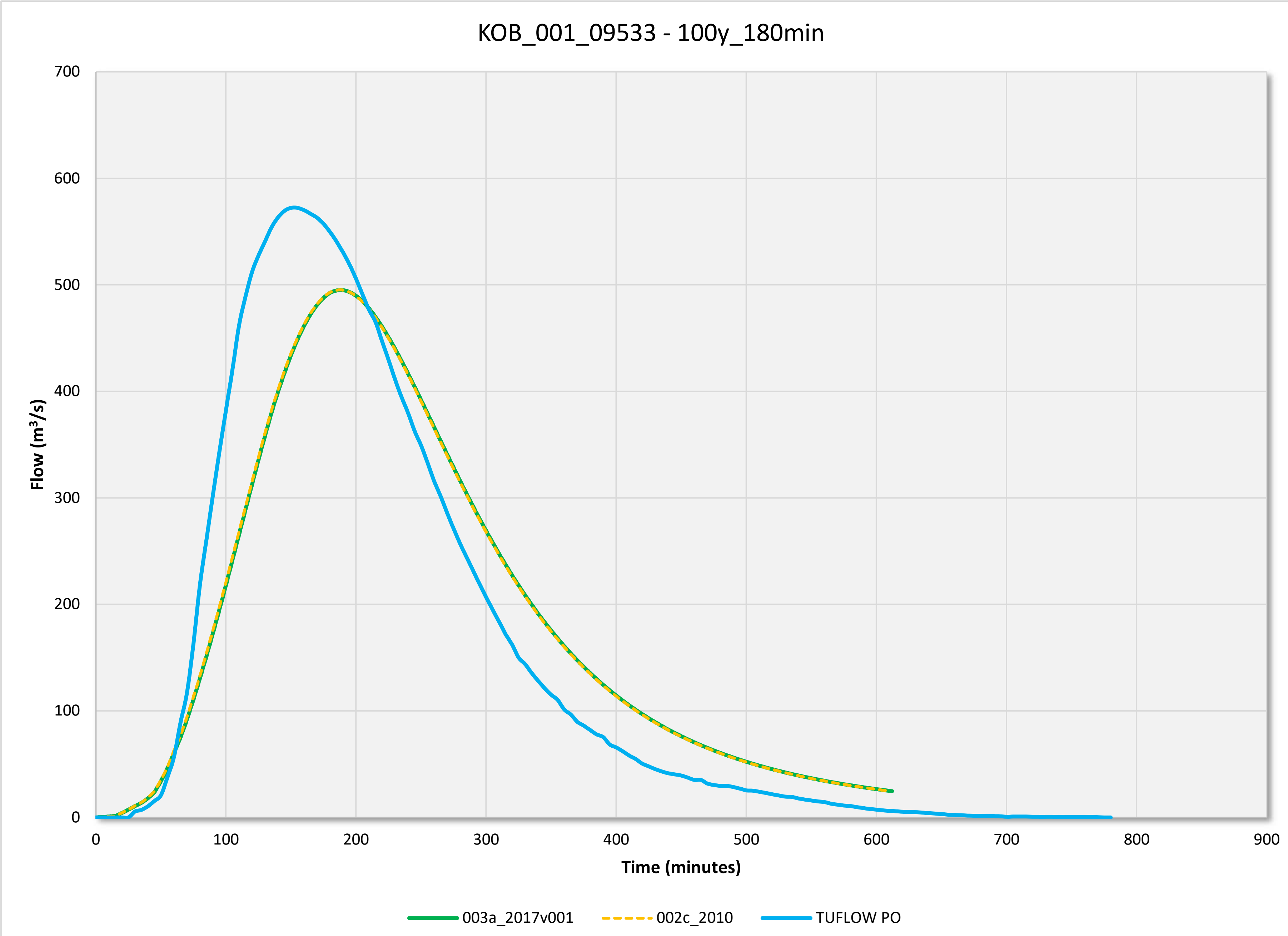

DEL_001_03830 - 100y_180min
Flow (m³/s)
0
100
200
300
400
500
600
700
800
Time (minutes)
0
100
200
300
400
500
600
700
800
003a_2017v001
002c_2010
TUFLOW PO



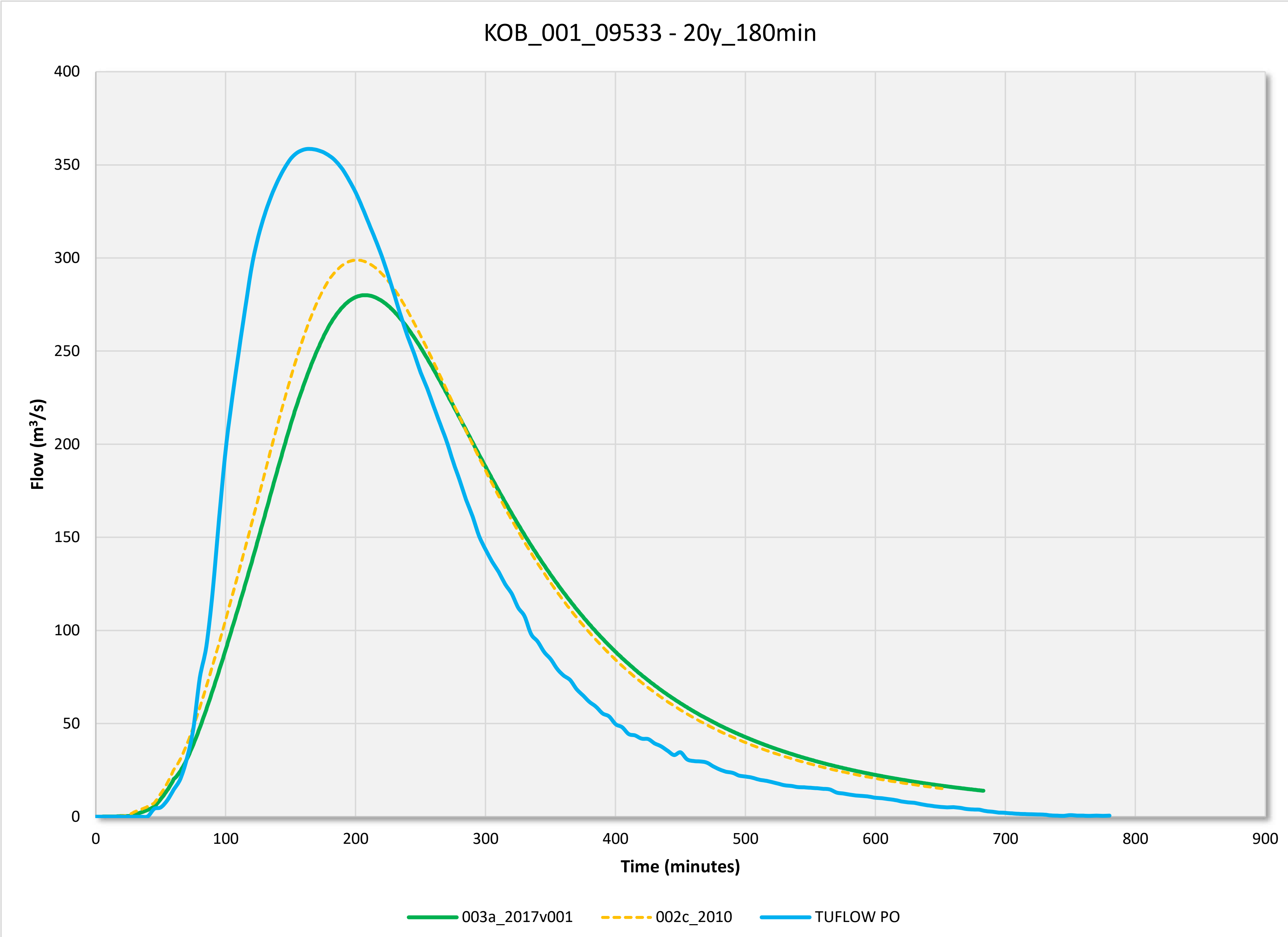
DEL_001_03830 - 20y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
400
450
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO

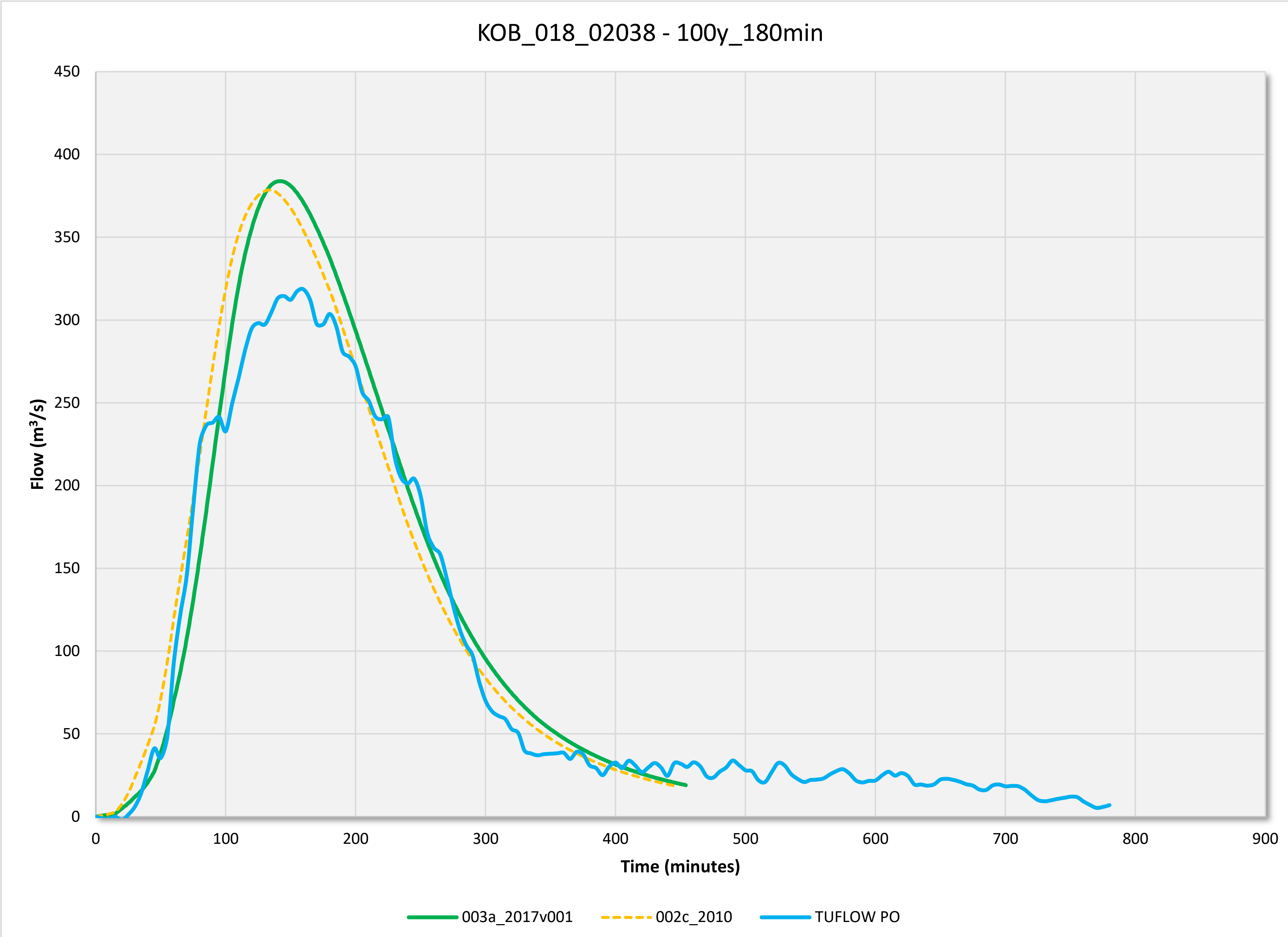

STO_001_03418 - 100y_180min
600
500
400
300
200
100
0
Flow (m³/s)
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


STO_001_03418 - 20y_180min
Flow (m³/s)
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

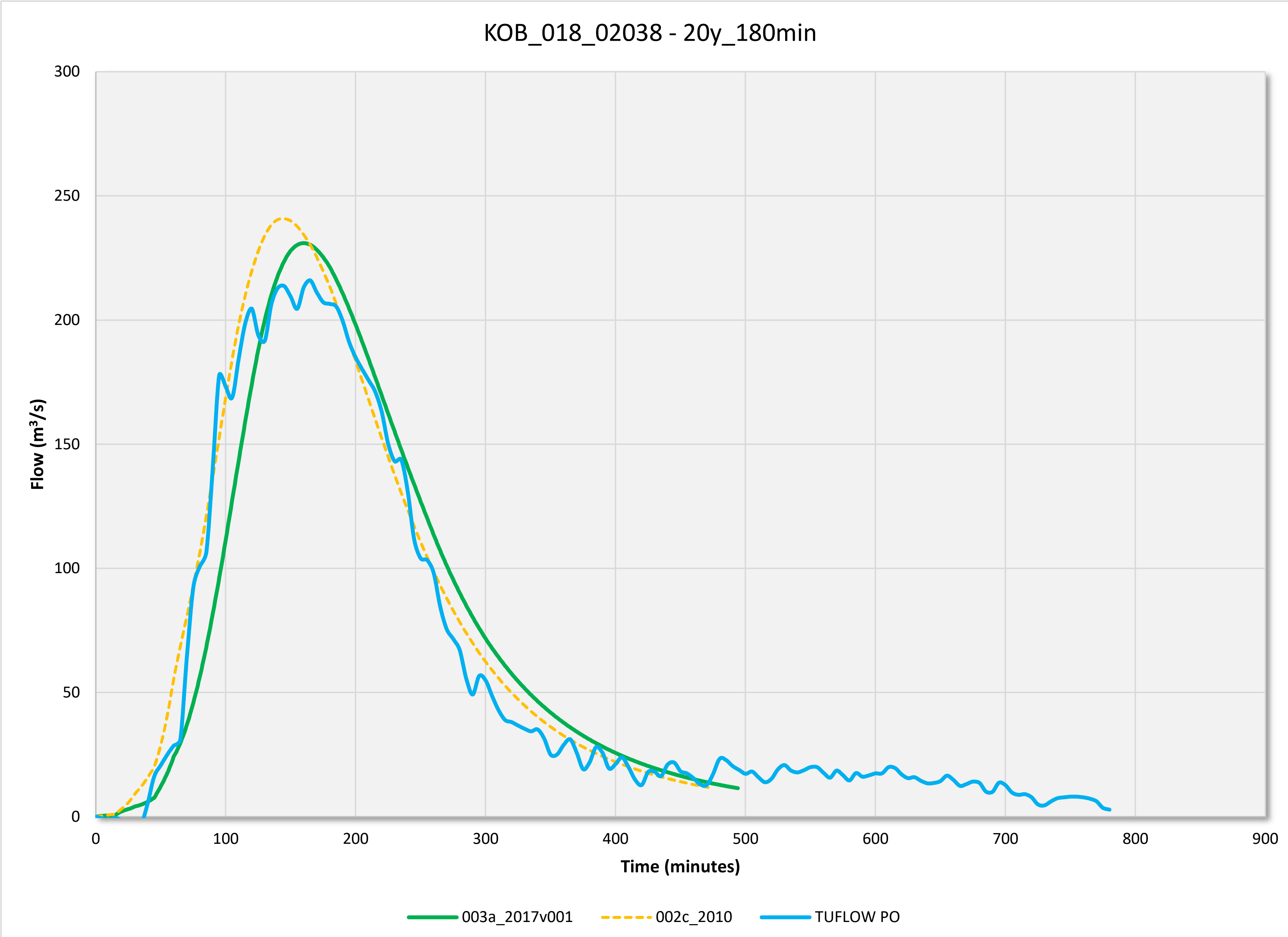


KOB_001_09533 - 100y_180min
Flow (m³/s)
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

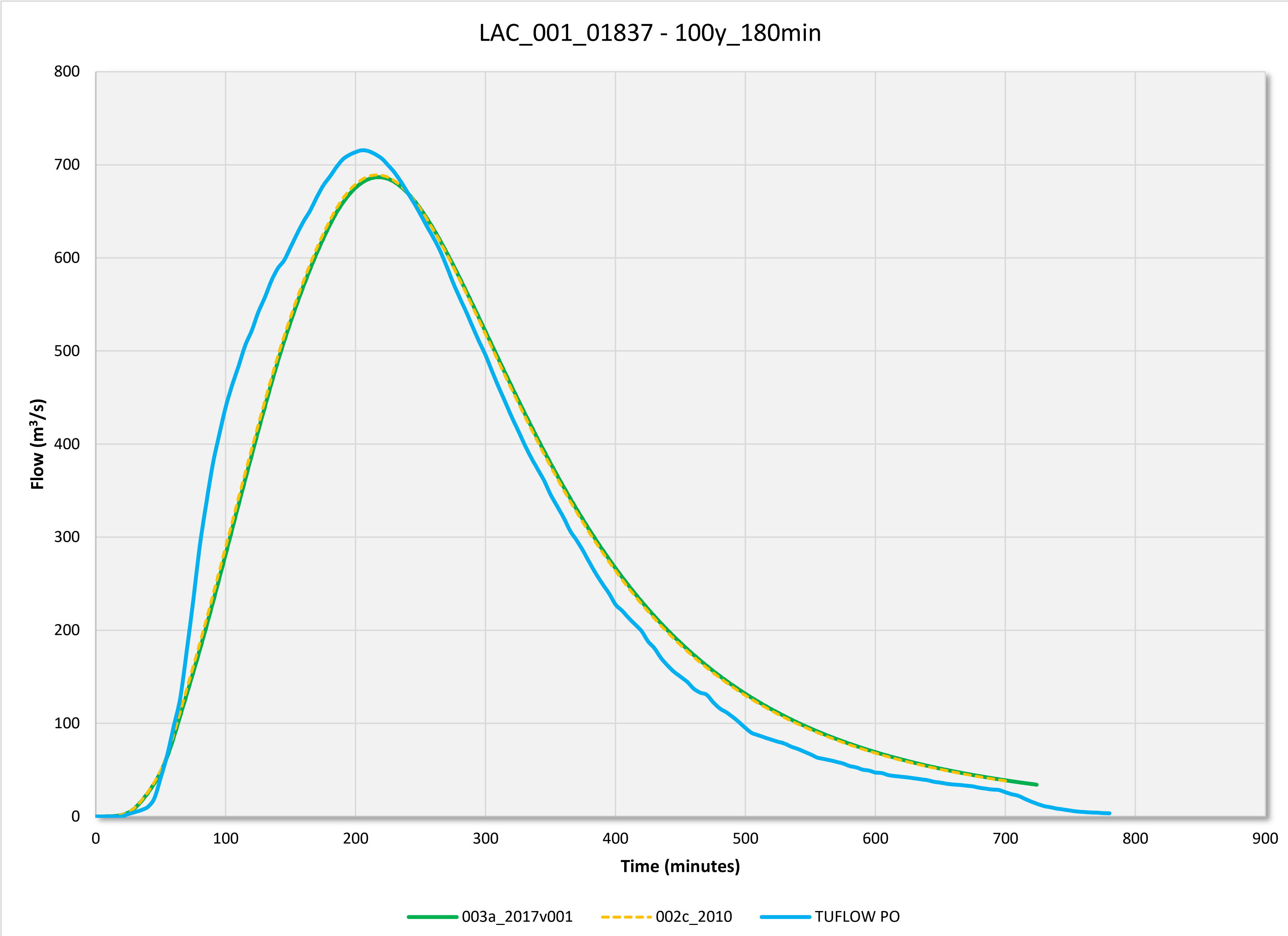

KOB_001_09533 - 20y_180min
Flow (m³/s)
Time (minutes)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO

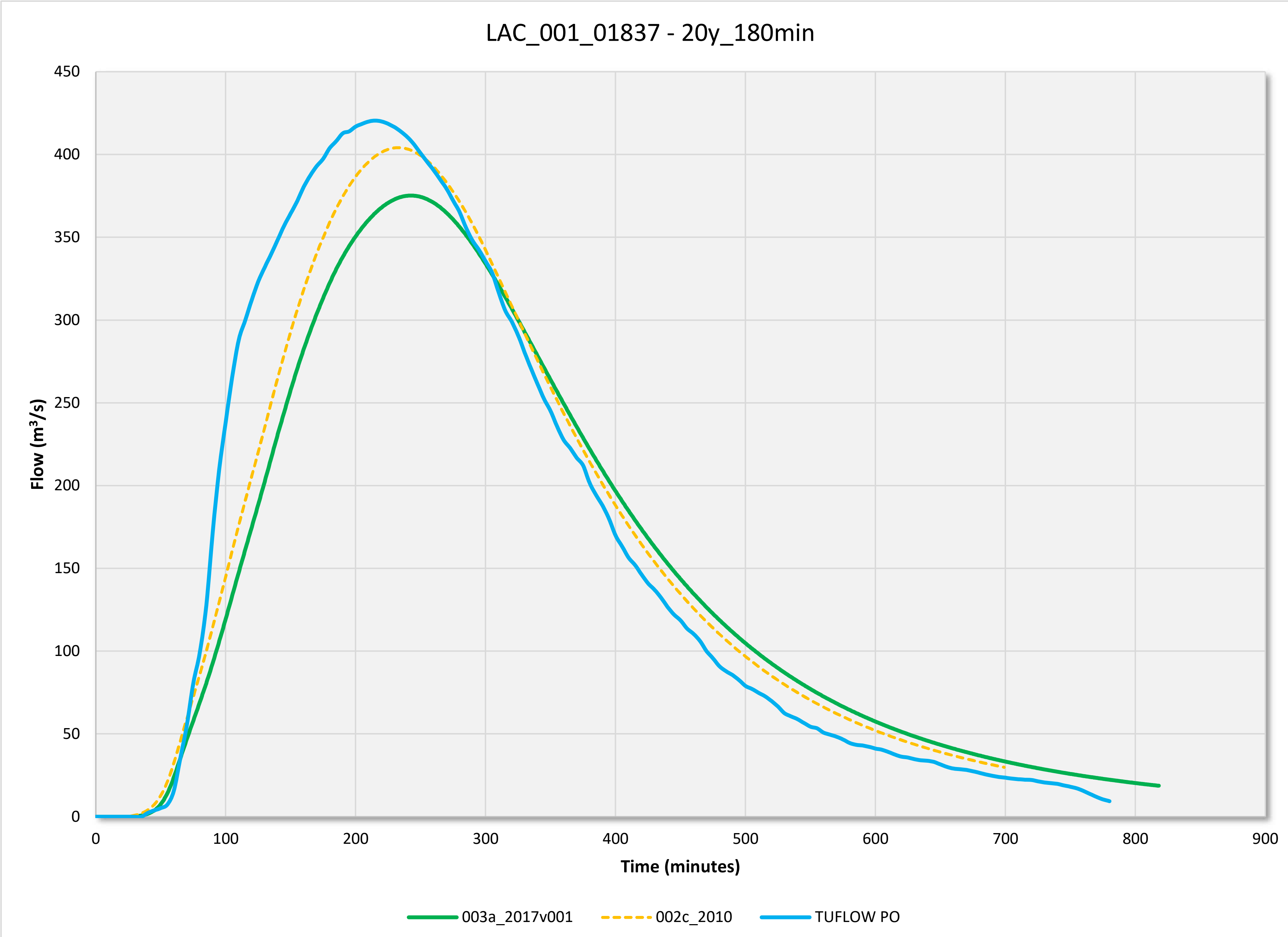


KOB_018_02038 - 100y_180min
Flow (m³/s)
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

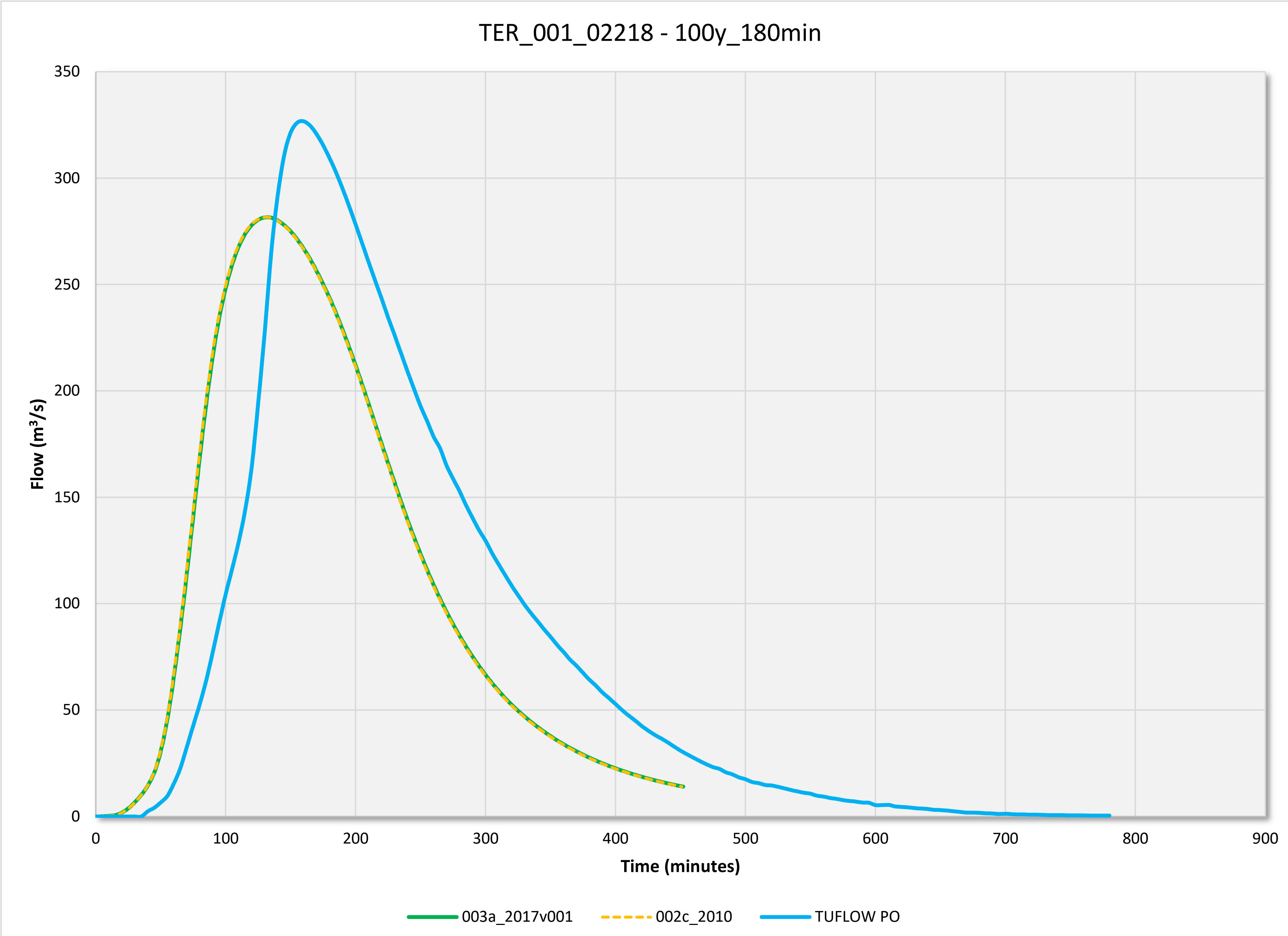


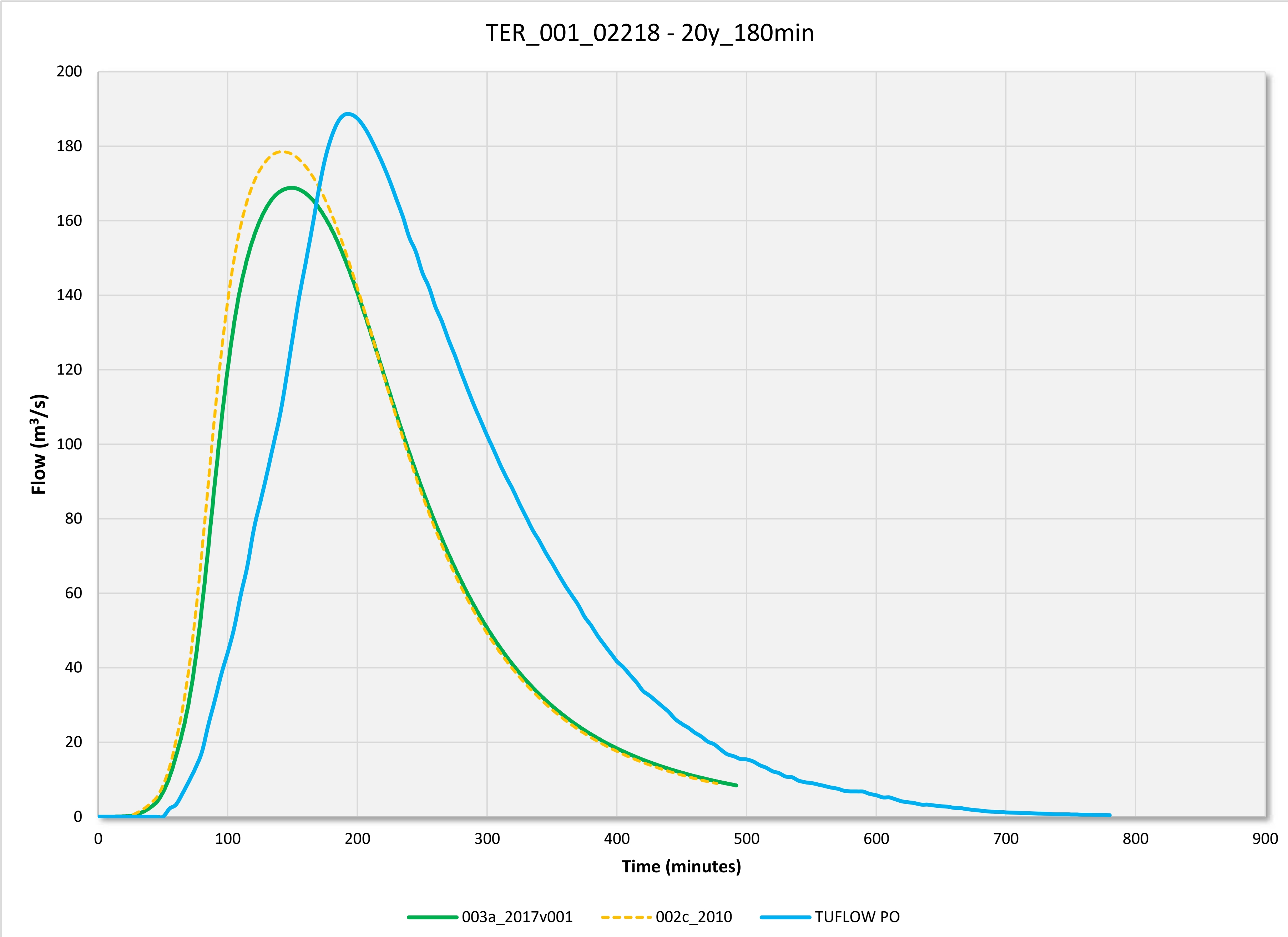
KOB_018_02038 - 20y_180min
Flow (m³/s)
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


LAC_001_01837 - 100y_180min
Flow (m³/s)
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

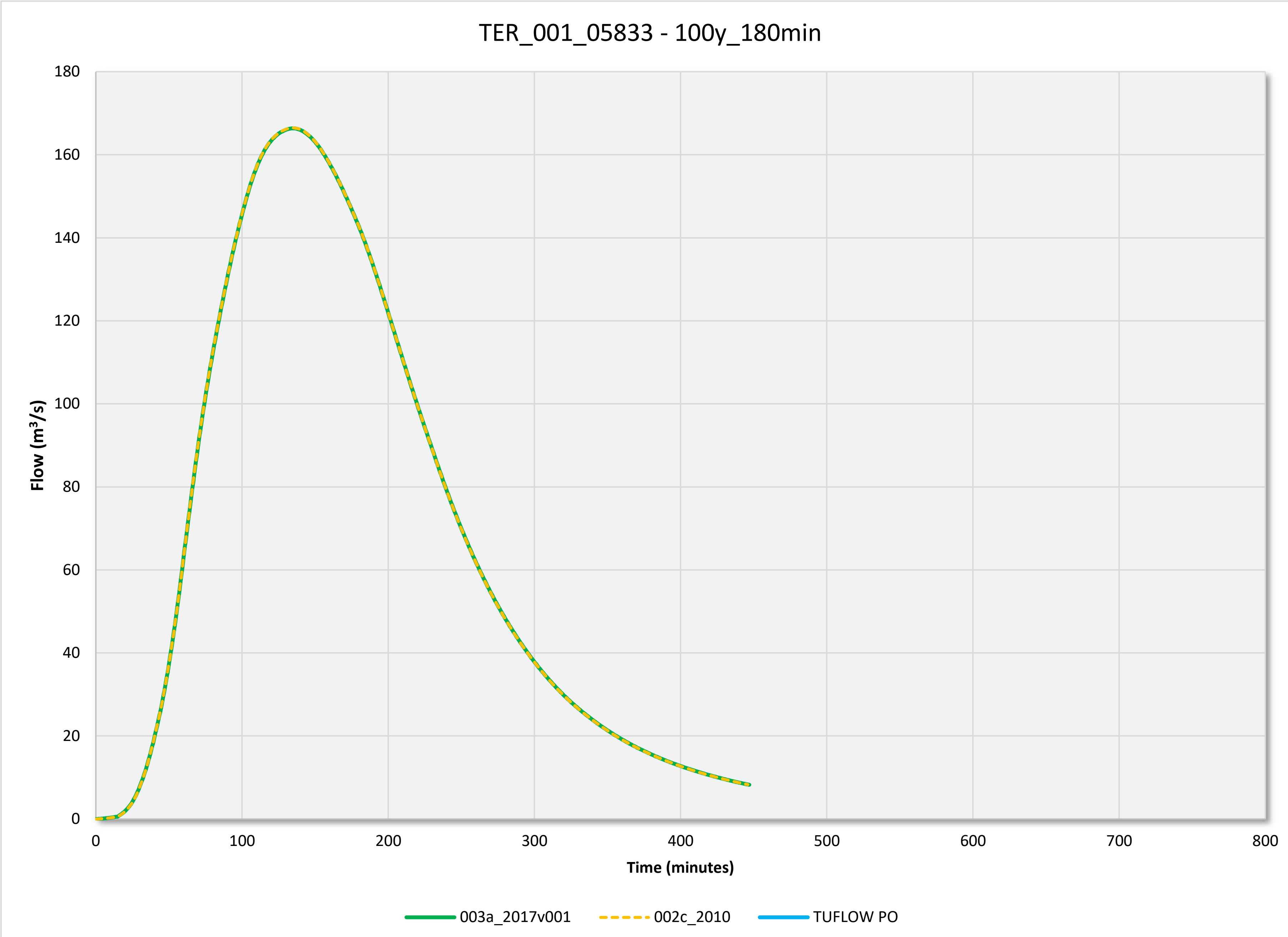


LAC_001_01837 - 20y_180min
Flow (m³/s)
450
400
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

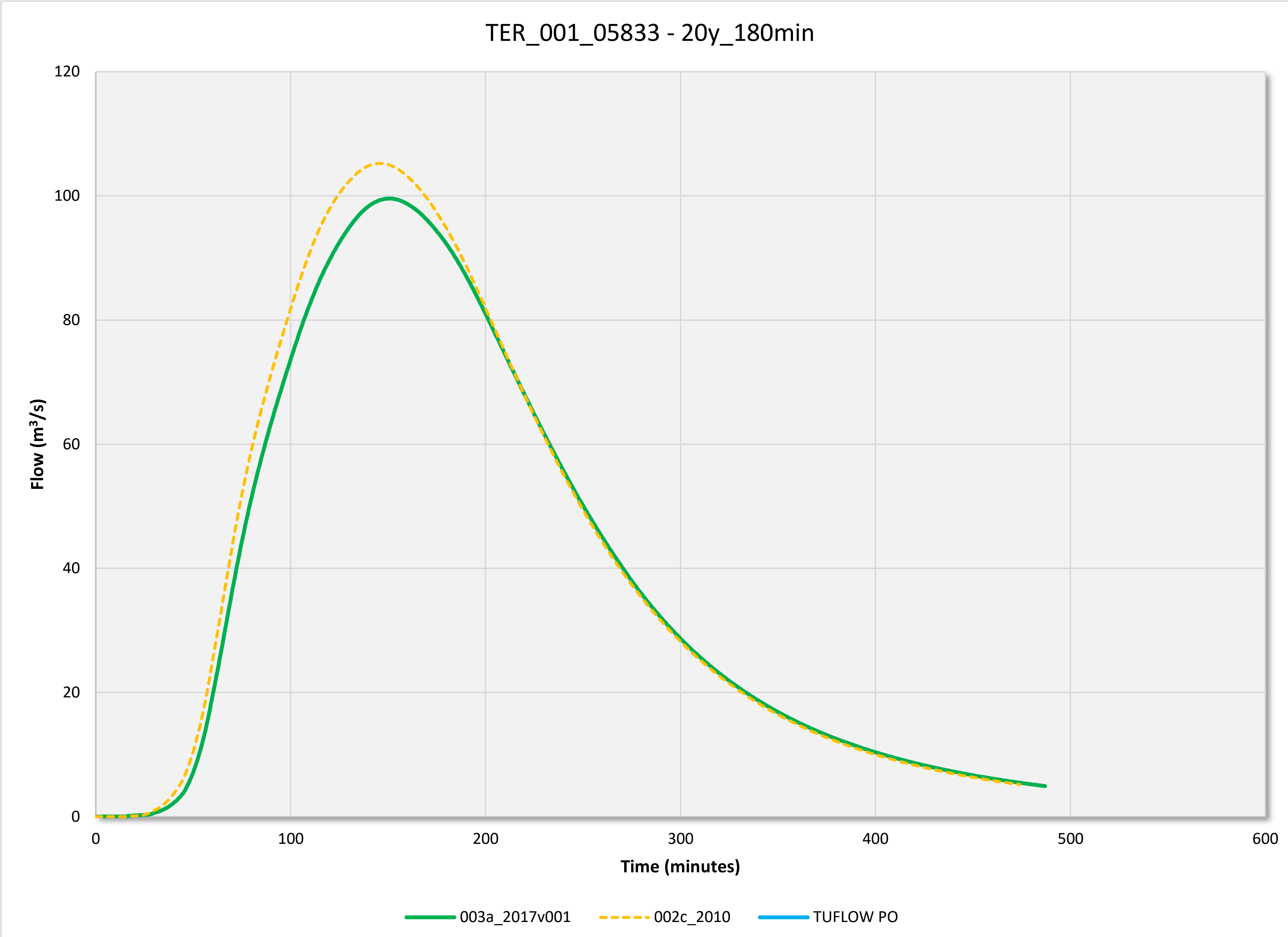

TER_001_02218 - 100y_180min
Flow (m³/s)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



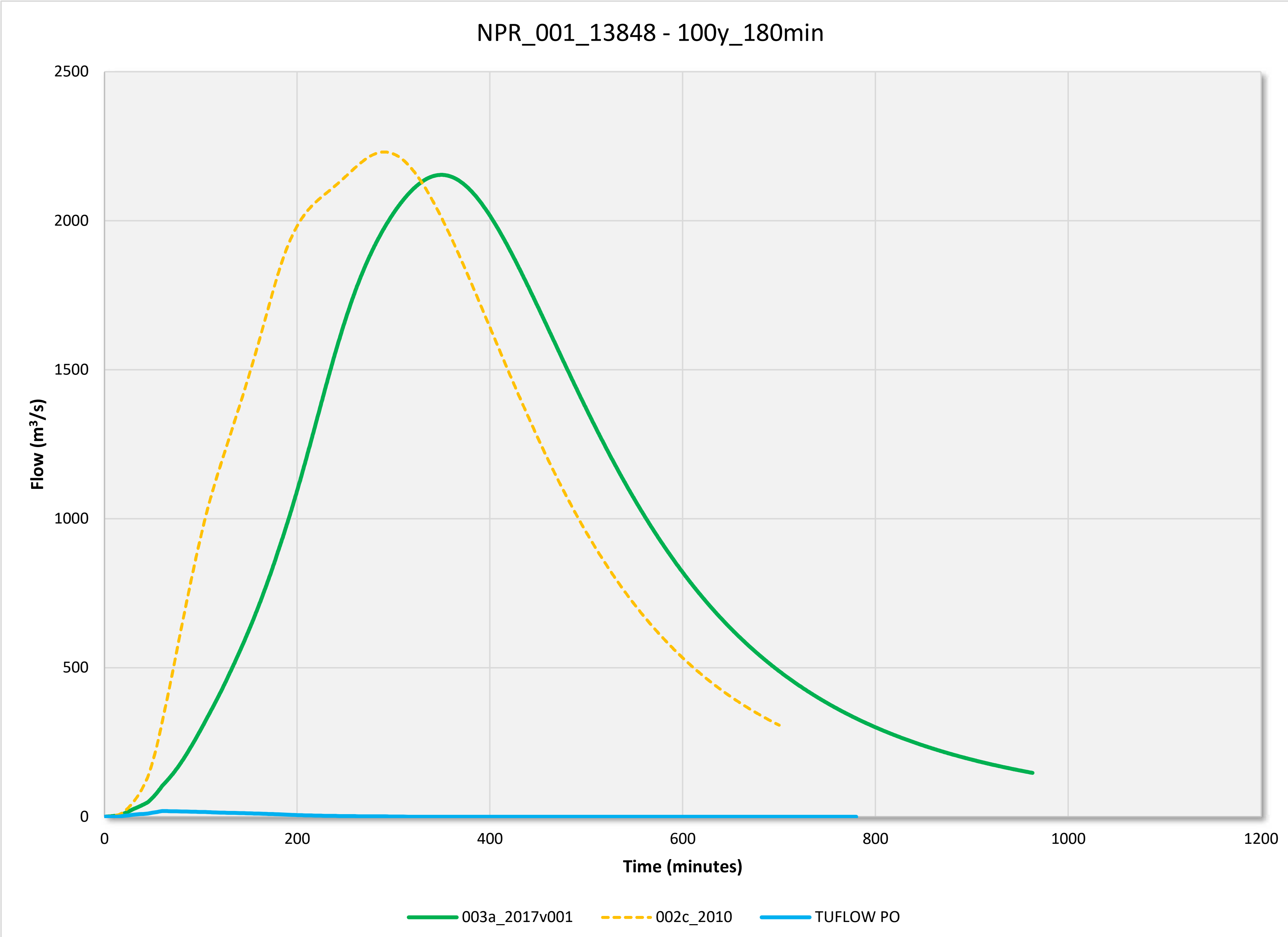
TER_001_02218 - 20y_180min
Flow (m³/s)
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

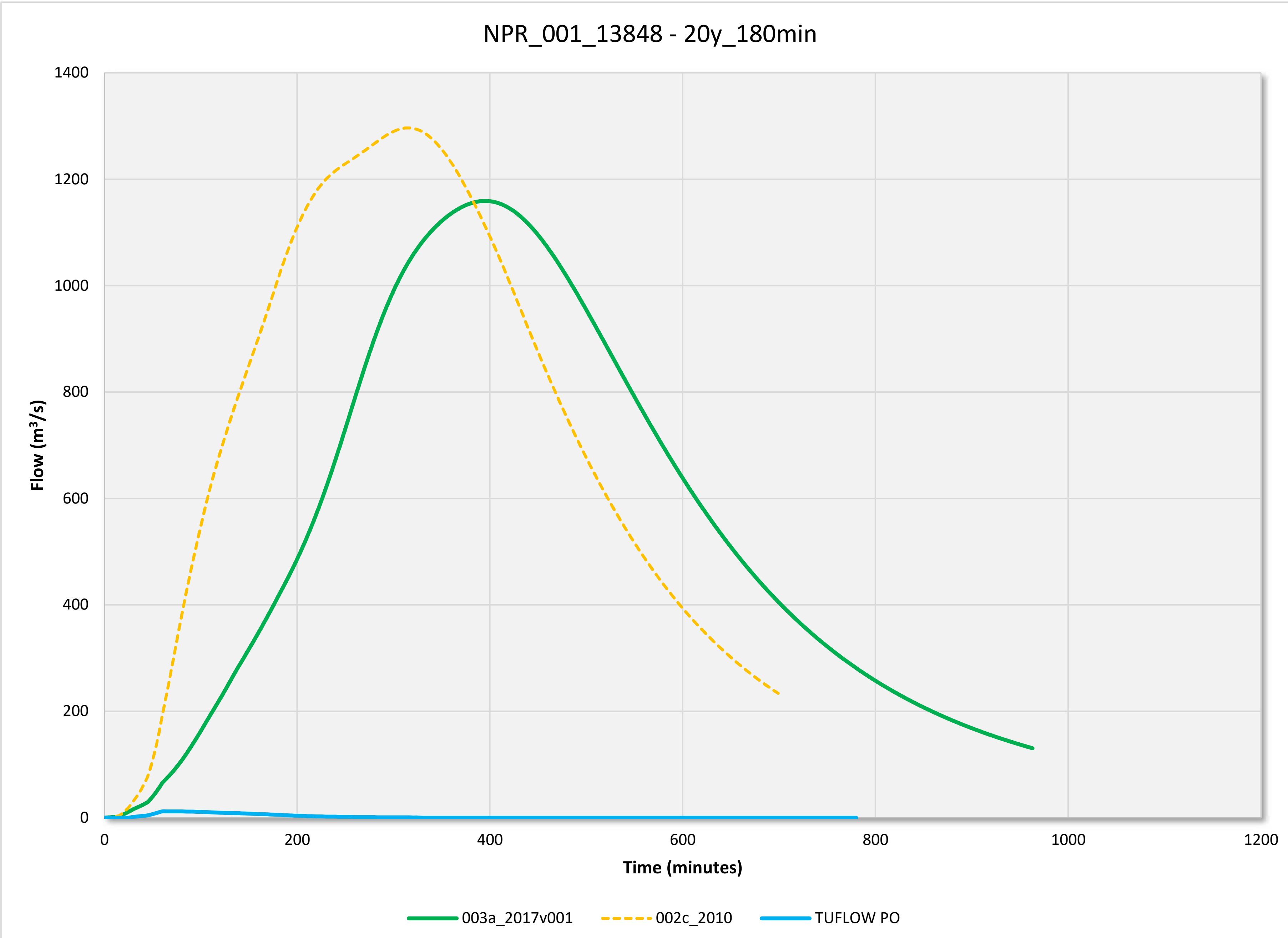


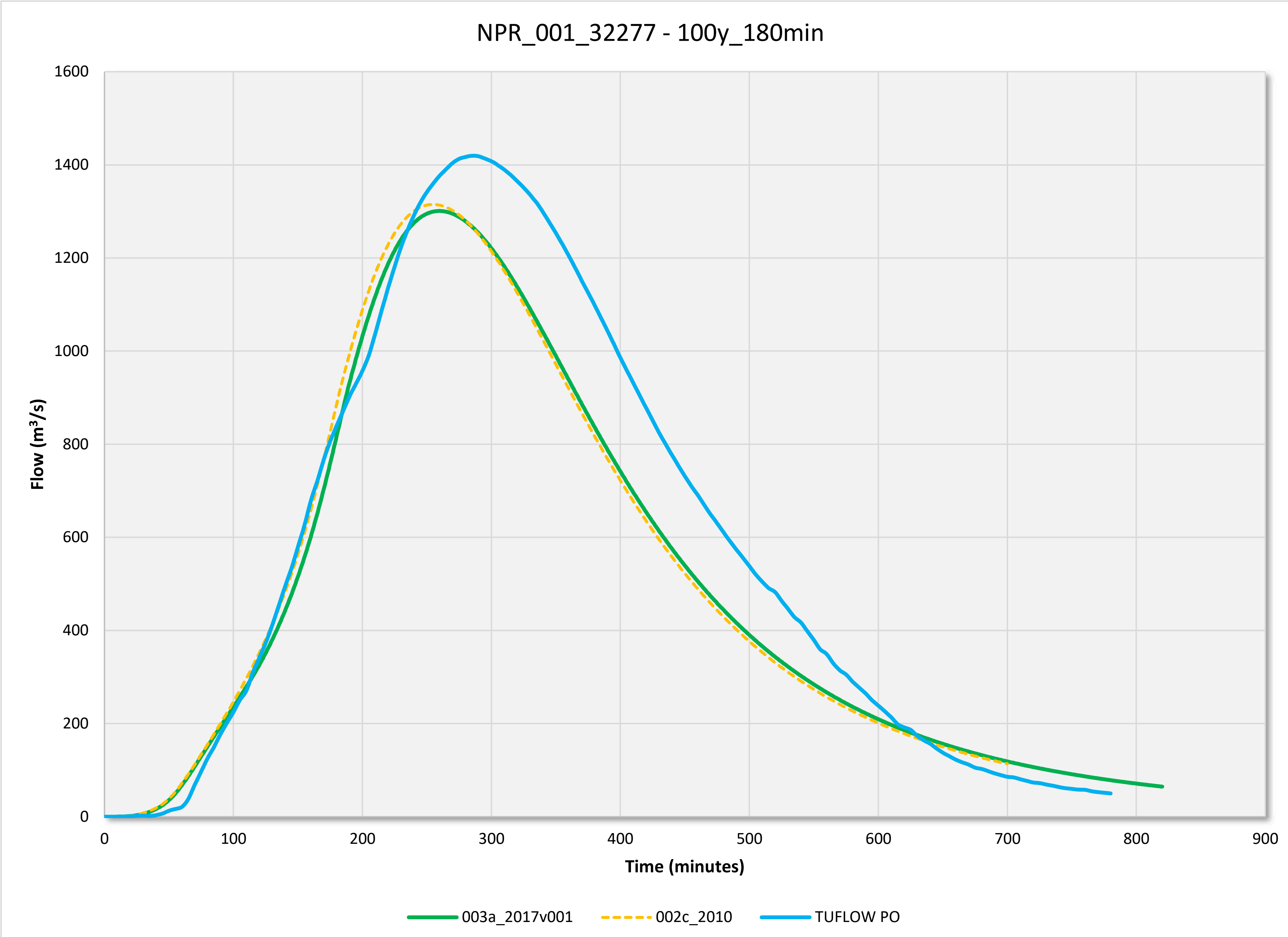
TER_001_05833 - 100y_180min
Flow (m³/s)
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



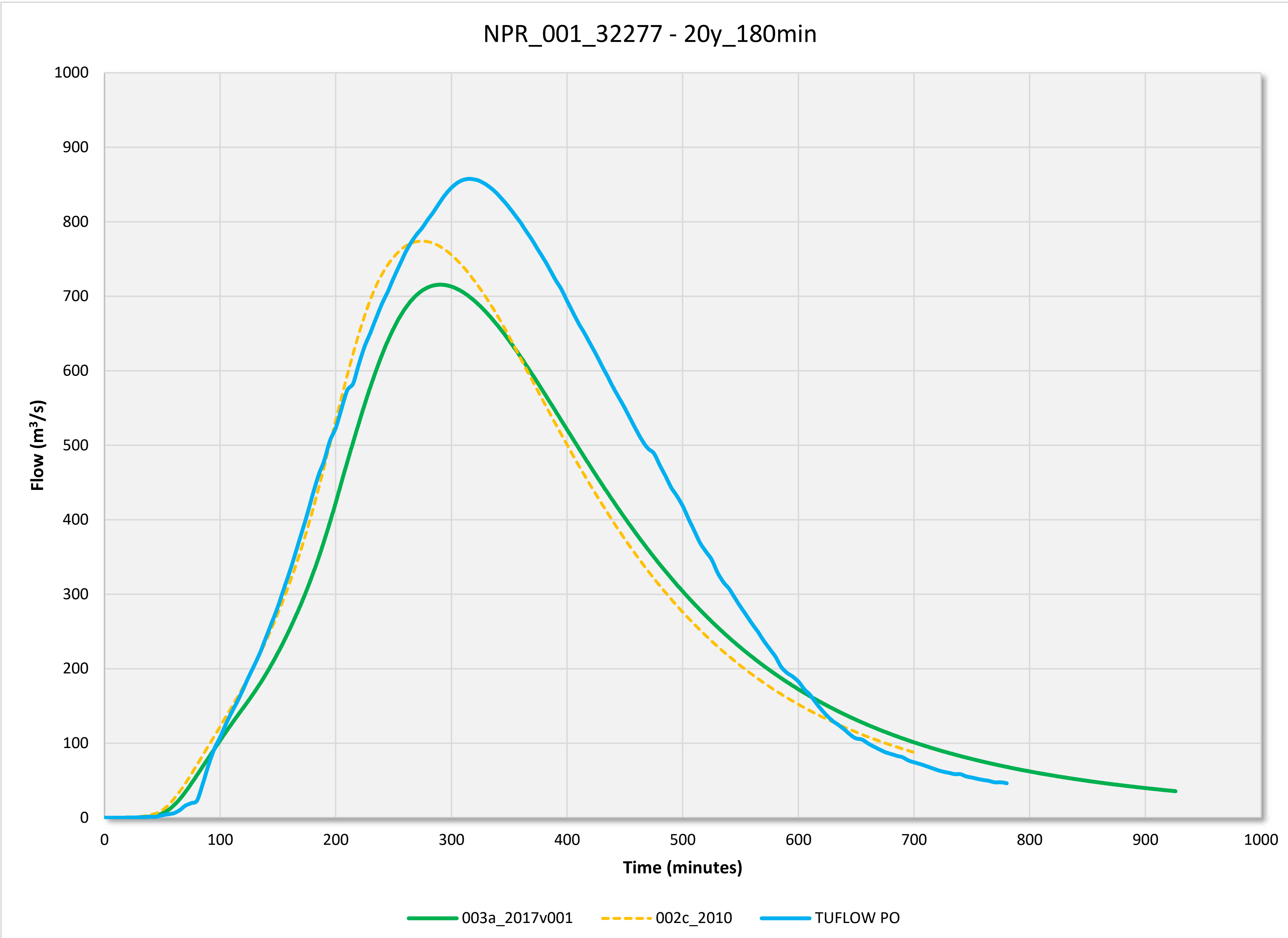
TER_001_05833 - 20y_180min
Flow (m³/s)
120
100
80
60
40
20
0
0
100
200
300
400
500
600
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


NPR_001_13848 - 100y_180min
Flow (m³/s)
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

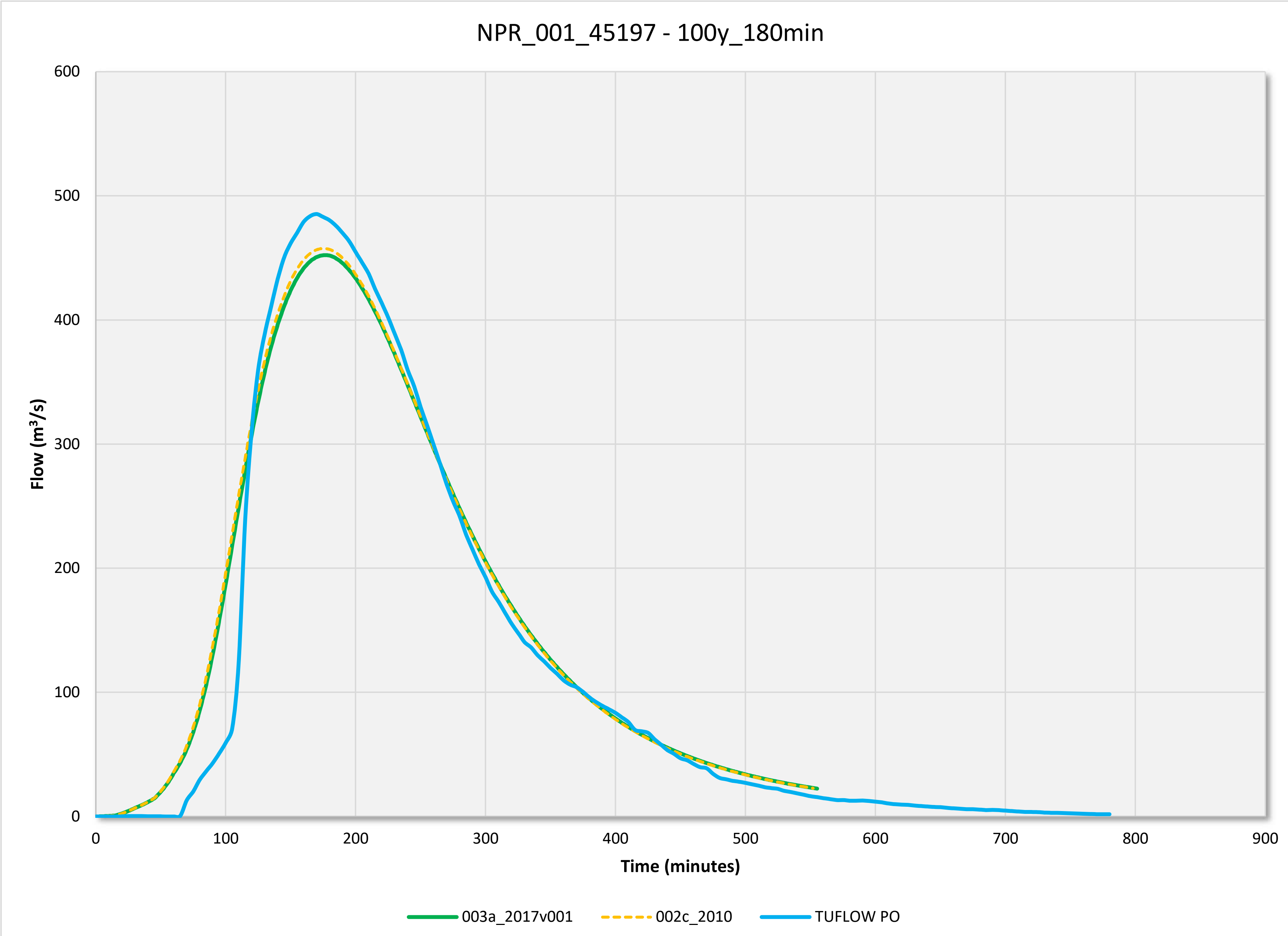

NPR_001_13848 - 20y_180min
Flow (m³/s)
0
200
400
600
800
1000
1200
1400
0
200
400
600
800
1000
1200
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

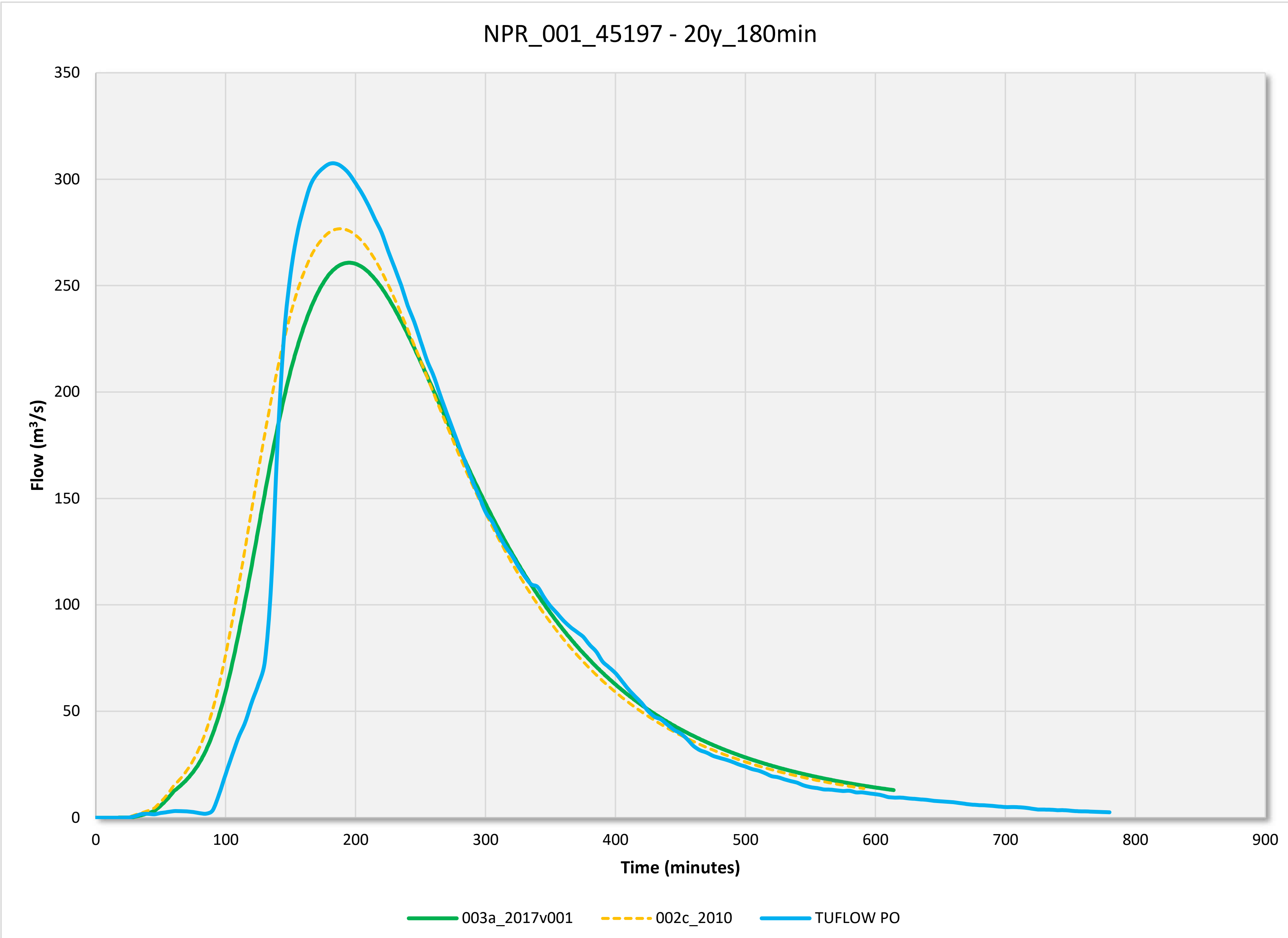


NPR_001_32277 - 100y_180min
Flow (m³/s)
Time (minutes)
0
200
400
600
800
1000
1200
1400
1600
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO

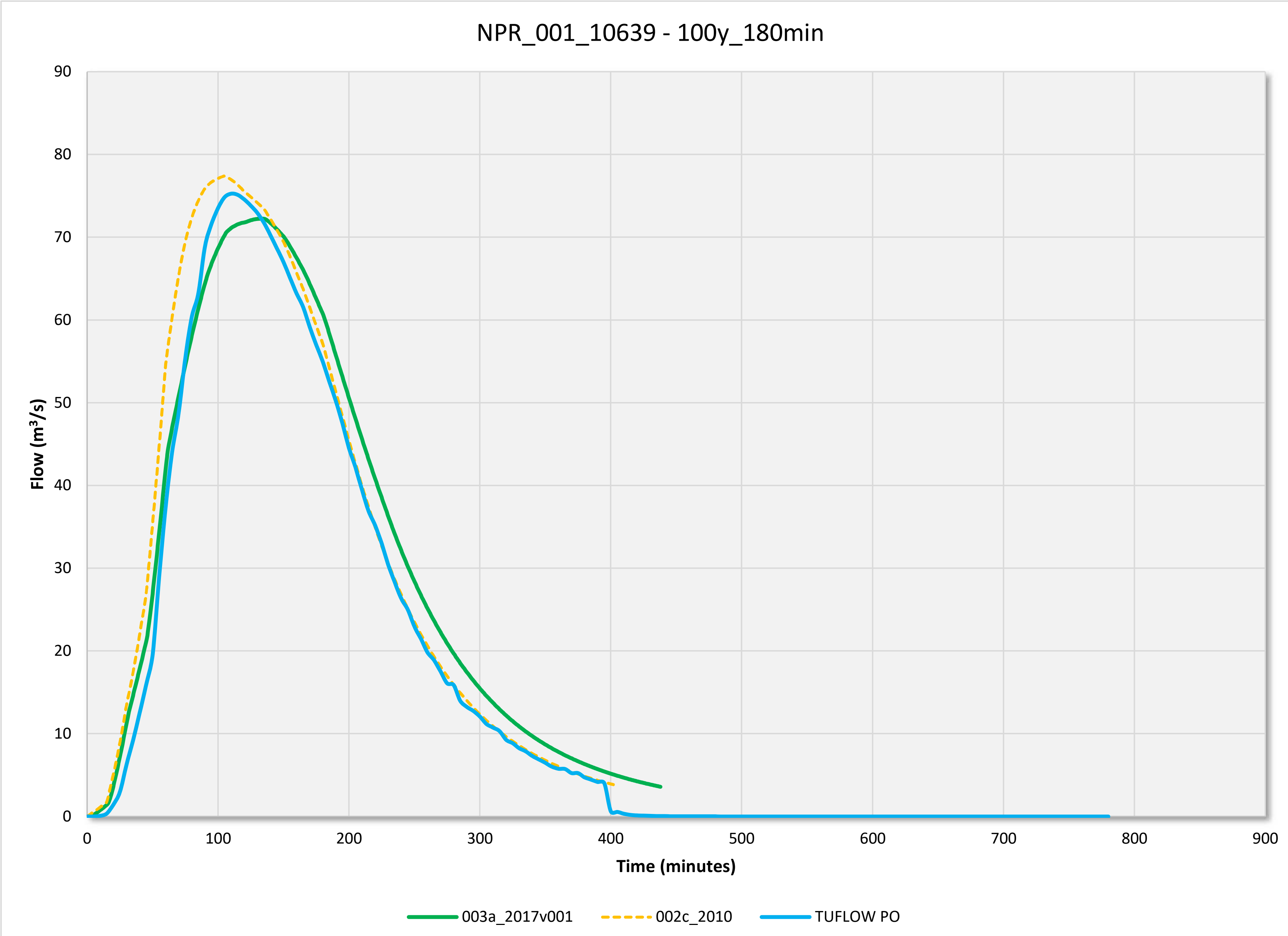


NPR_001_32277 - 20y_180min
Flow (m³/s)
0
100
200
300
400
500
600
700
800
900
1000
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

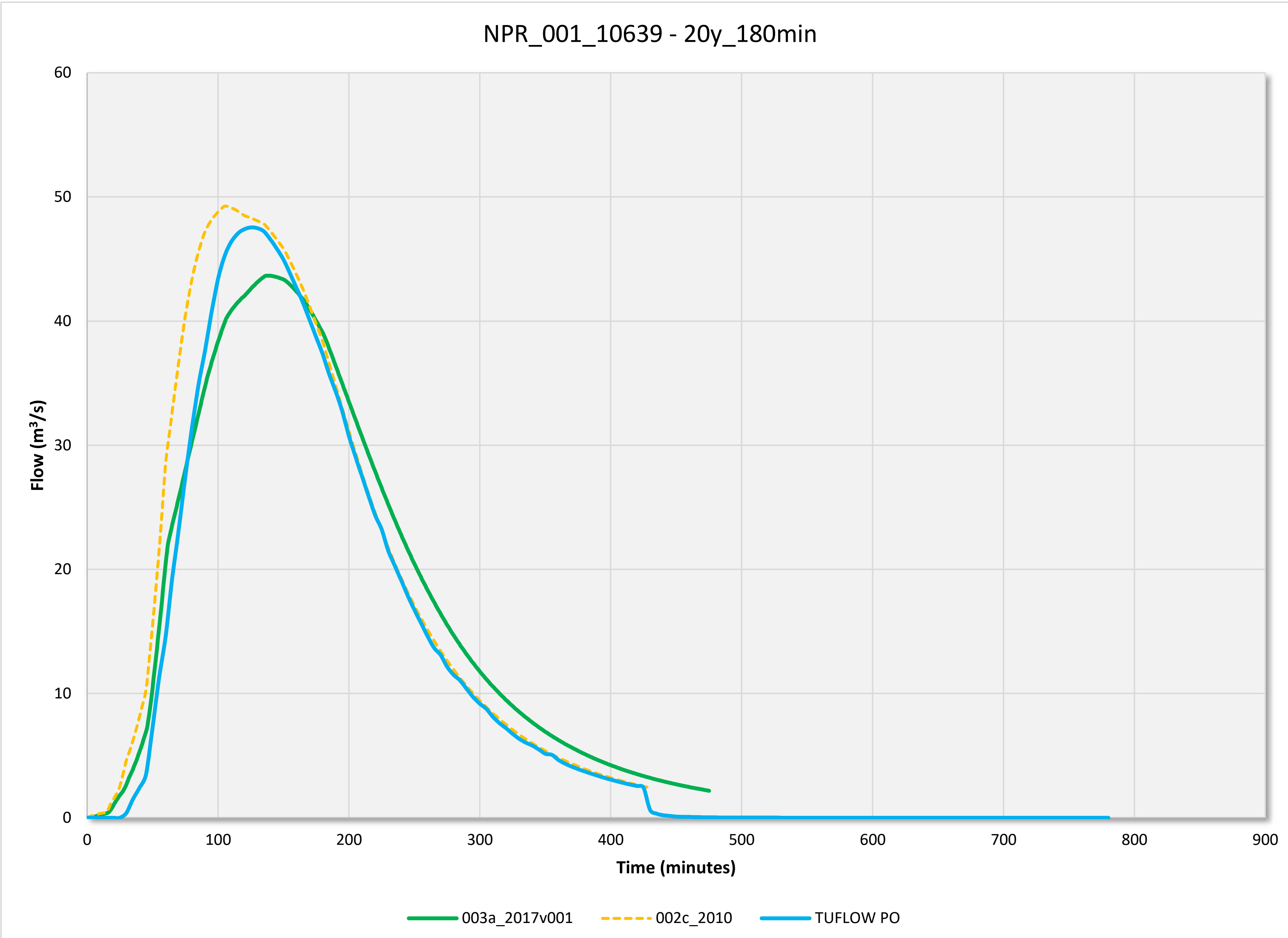

NPR_001_45197 - 100y_180min
Flow (m³/s)
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO

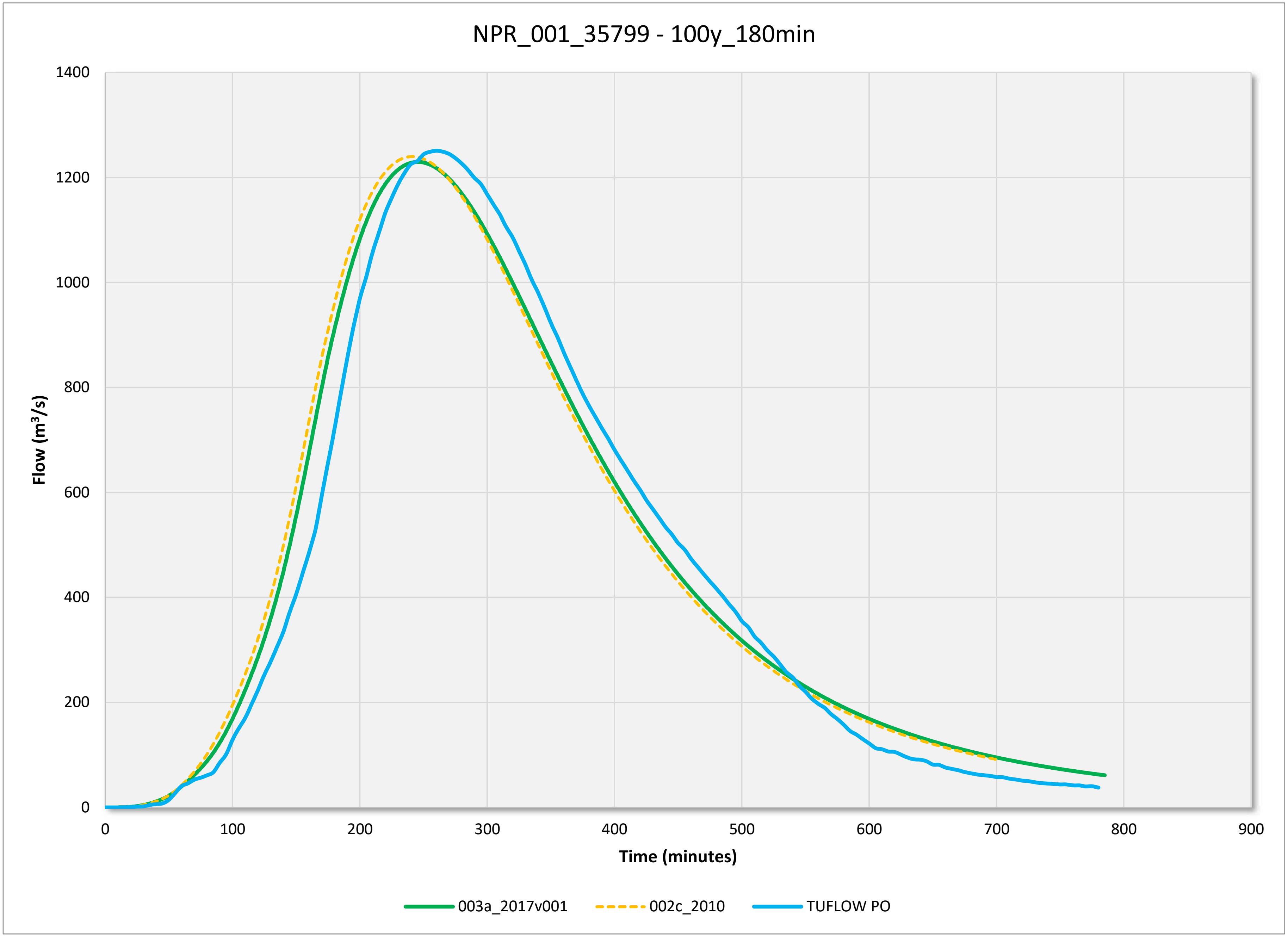


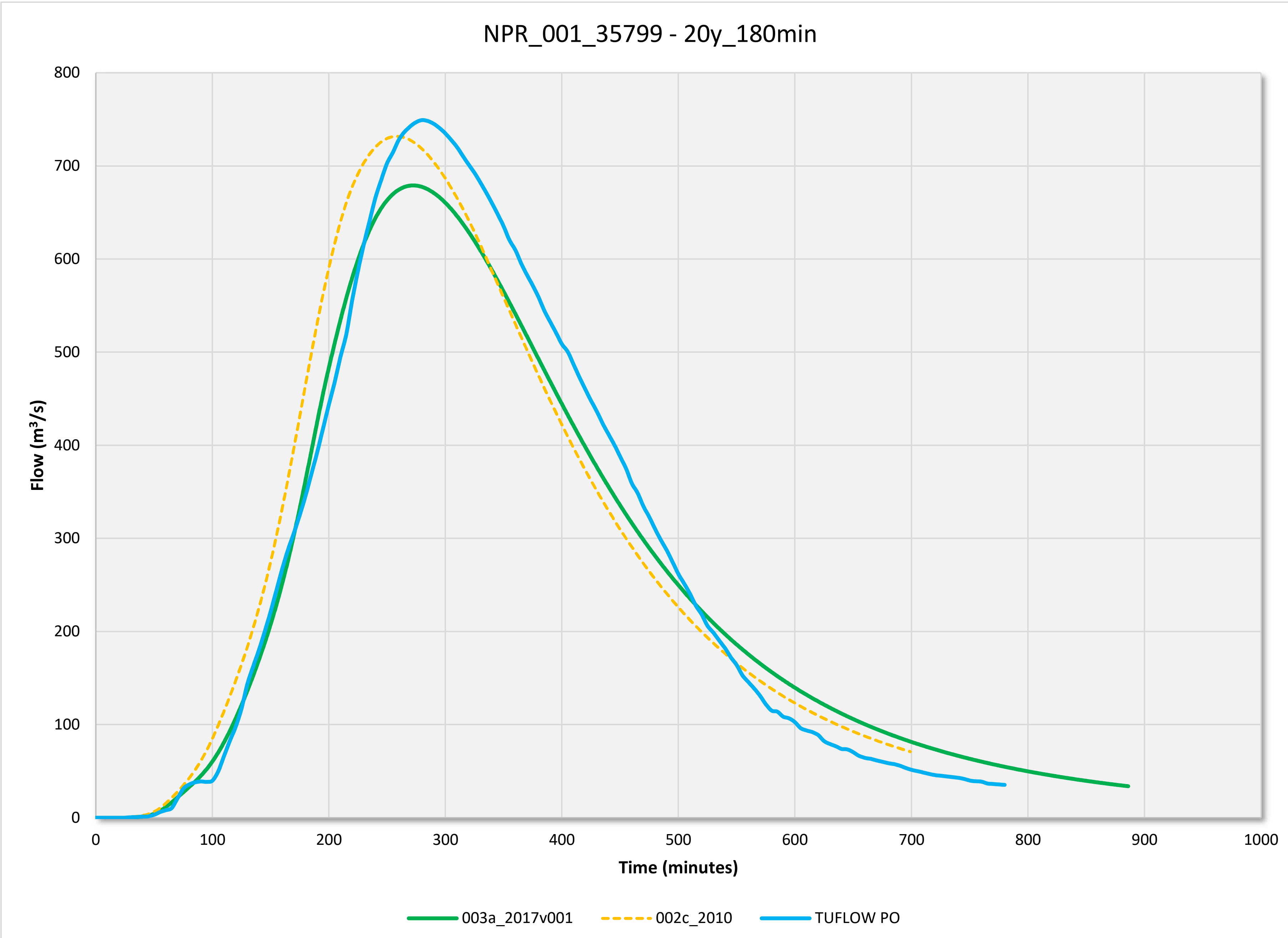
NPR_001_45197 - 20y_180min
Flow (m³/s)
350
300
250
200
150
100
50
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



NPR_001_10639 - 100y_180min
Flow (m³/s)
0
10
20
30
40
50
60
70
80
90
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO


NPR_001_10639 - 20y_180min
Flow (m³/s)
Time (minutes)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700
800
900
003a_2017v001
002c_2010
TUFLOW PO


NPR_001_35799 - 100y_180min
Flow (m³/s)
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO



NPR_001_35799 - 20y_180min
Flow (m³/s)
0
100
200
300
400
500
600
700
800
0
100
200
300
400
500
600
700
800
900
1000
Time (minutes)
003a_2017v001
002c_2010
TUFLOW PO