Flanders
State of
the Art

00_162_4-2
FHR reports

Modelling water availability and water allocation strategies in the Scheldt basin

Sub report 4-2
Developing a rainfall-runoff model of the Meuse – NAM Meuse

DEPARTMENT
MOBILITY &
PUBLIC
WORKS

www.flandershydraulicsresearch.be

Modelling water availability and water allocation strategies in the Scheldt basin

Sub report 4-2 – Developing a rainfall-runoff model of the Meuse – NAM Meuse

Maroy, E.; Michielsen, S.; Velez, C.; Pereira, F.; Nossent, J.; Mostaert, F.

Flanders Hydraulics Research
Flanders State of the Art

Legal notice

Copyright and citation

D/2021/3241/133

This publication should be cited as follows:

Maroy, E.; Michielsen, S.; Velez, C.; Pereira, F.; Nossent, J.; Mostaert, F. (2021). Modelling water availability and water allocation strategies in the Scheldt basin: Sub report 4-2 – Developing a rainfall-runoff model of the Meuse – NAM Meuse. Version 2.0. FHR Reports, 00_162_4-2. Flanders Hydraulics Research: Antwerp

Document identification

Customer:	Flanders Hydraulics Research	Ref.:	WL2021R00_162_4-2
Keywords (3-5):	Rainfall-runoff modelling, hydrology, Meuse, NAM		
Knowledge domains:	Water management > Hydrology > Conceptual Models > Numerical modelling		
Text (p.):	36	Appendices (p.):	78
Confidentiality:	☒ No	☒ Available online	

Author(s):	Maroy, E.; Michielsen, S.; Velez, C.

Control

	Name	Signature
Reviser(s):	Nossent, J.	Getekend door:Jiri Nossent (Signature) Getekend op:2021-07-08 10:16:48 +02:0 Reden:Ik keur dit document goed Jiri Nossent
Project leader:	Pereira, F.	Getekend door:Fernando Pereira (Signat Getekend op:2021-07-02 09:36:00 +02:0 Reden:Ik keur dit document goed Fernando Pereira

Approval

Head of Division:	Mostaert, F.	Getekend door:Frank Mostaert (Signatur Getekend op:2021-07-01 17:43:03 +02:0 Reden:Ik keur dit document goed Frank Mostaert

Abstract

In order to correctly simulate the water availability in the Albert Canal and the Campine Canals, it is important to correctly simulate the flow in the Meuse river. The river is the source for this vast canal system. If it is possible to simulate the hydrology of the Meuse basin, it will be possible to model the water balance of the canal system for a period of over 40 years. The modelling has been done using the NAM software (©DHI).

The Meuse catchment is split up in 11 sub catchments. One big catchment of the Meuse itself upstream from Profondeville, 7 catchments of different scale of the tributaries downstream of Profondeville and 3 smaller catchments representing the ungauged area downstream Profondeville. Except for the catchment upstream from Profondeville, the catchments are calibrated separately to find an optimal parameter set. To assess the parameters for modelling the upstream catchment, the latter was split in 5 sub catchments which were calibrated separately. However, for the purpose of the water availability modelling of the Albert Canal and Campine canals, the area upstream from Profondeville is simulated by using the parameters of the biggest sub catchment (i.e. the French part of the Meuse catchment).

The optimization during calibration is performed based on an automatic procedure, followed by a visual control. During the optimization routine the parameter sets are selected based on 2 criteria: (1) absolute error on cumulated total flow at each time step, and (2) logarithmic Nash-Sutcliff efficiency. The first criterion aims to model the global flow pattern, the latter focuses mainly on the low flows.

In general the simulation of the hydrology of the Meuse catchment gives fairly good results bearing in mind that it is used for simulations on a regional scale.

Contents

List of tables

List of figures

1 Introduction

The objective of the modelling tasks detailed in this report is to provide long discharge time series to simulate the water availability in the Albert Canal and the Campine Canals. The hydrology of the Meuse basin was modelled with the NAM software (©DHI) using historical rainfall and evapotranspiration timeseries. Simulated discharge in the Meuse could then be used as input to a MIKE Basin model to simulate the water balance of the canal system for a period of over 40 years.

First, the Meuse catchment was split up in 11 subcatchments that needed to be modelled. One big catchment of the Meuse itself upstream from Profondeville, 7 catchments of tributaries downstream of Profondeville and 3 catchments representing the remaining ungauged areas (Section 2).

Rainfall and evapotranspiration were then averaged over the selected catchments, according to the Thiessen polygon spatial interpolation method. Because of the large scale and the long term nature of the study, a daily time step was used (Section 3). For consistency reasons, calibration was also based on daily time series.

The 10 parameters of the rainfall-runoff lumped model NAM were calibrated for the gauged catchments (Section 4), based on an automatic procedure followed by a visual control (section 53.4). During the optimization routine the parameter set is selected based on 2 criteria: (1) the absolute error on cumulative total flow at each time step, and (2) the logarithmic Nash-Sutcliff efficiency. The first criterion aims to model the global flow pattern, the latter focuses mainly on the low flows.

Once the parameters were calibrated for each subcatchments, flow was simulated for 47 years (1967-2013). Ungauged catchments are modelled using parameter values of a nearby catchment with similar characteristics. Flow from the catchment in Profondeville is simulated by using the parameters of the biggest subcatchment (i.e. the French part of the Meuse catchment). Results are validated for most of the basin using control discharge data in Amay (before confluence of the Meuse and the Ourthe) (Section 6.7).

Looking at statistical goodness-of-fit indicators and through visual analysis, NAM-simulated total dischage for the Meuse and its tributaries can be used with confidence for the study purposes: modelling of water availability at a regional scale.

2 Pre-processing of discharge timeseries

2.1 Overview of the Meuse basin

In order to produce discharge time series as inputs for the water allocation model of the Meuse-canals system between Monsin and Maastricht, we need to model the hydrology of the Meuse contributing catchments in France and Wallonia. The Meuse basin is the second biggest hydrographic district of Belgium (about 20.450 km² in Visé). The Meuse river has its source in France in Pouilly-en Bassigny and enters Belgium in Agimont. The gauging station of Chooz, located in France, is the closest to the Walloon border. The main tributaries of the Walloon Meuse are the Sambre (about 2.700 km²), meeting the Meuse in Namur, and the Ourthe (about 3.600 km²) in Liège.

Figure 1 (on the next page) shows a map of the Meuse basin in Wallonia, with a first selection of flow measuring stations (yellow dots) and their corresponding catchments. The catchment delineation was based on the GIS resources of the Walloon region (SPW). The surface area calculated based on these polygons matches closely the data published by SPW on the "Infocrue" website for each catchment (when available).

Our first selection of stations consists of 17 usable stations on the Meuse and the Sambre itself, and on their different tributaries (Table 1). Chooz station (located in France) is considered to measure the entering flow of the Meuse at the French border, while Solre station is recording the entering flow for the Sambre.

Table 1 – List of gauging stations on the Meuse and its tributaries for the calibration of the hydrological models

Catchment	Station/River	Area (km²)	Subcatchment ID	Available data	Owner
Hoyoux	**Marchin/Hoyoux**	**242**	**W11HOY5990**	**1/01/2001-31/12/2013**	**DGO2**
Mehaigne	**Wanze/Mehaigne**	**356**	**W11MEH5820**	**1/01/2001-31/12/2013** (except 2003)	**DGO3**
Haute Meuse	Herock/Lesse	1156	W11LES6610	1/01/2001-31/12/2013	DGO3
Haute Meuse	Yvoir/Bocq	230	W11BOC8134	1/01/1979-31/12/2014	DGO2
Haute Meuse	Warnant/Molignée	125	W11MOL8163	1/01/1969-31/12/2014	DGO2
Haute Meuse	Hastières/Hermeton	166	W11HER8622	1/01/1969-31/12/2014	DGO2
Haute Meuse	**Chooz/Meuse**	**10120**	**F11MAA8702**	**1/01/1990-31/12/2014**	**DGO2**
Ourthe	**Angleur 2 bis/Ourthe**	**3612**	**W11OUR5805**	**1/01/1974-31/12/2014**	**DGO2**
Sambre	Aiseau/Biesme	78	W11BIE5442	1/01/2001-31/12/2013	DGO3
Sambre	Thuin/Biesme l'eau	86	W11BLE6630	1/01/2001-31/12/2013	DGO3
Sambre	Jemeppes-s-O/Orneau	211	W11ORN7241	1/01/2007-31/12/2013	DGO3
Sambre	Jamioulx/Eau d'Heure	322	W11EDH7711	1/01/1995-31/12/2014	DGO2
Sambre	Wiheries/Hantes	142	W11HAN7944	1/01/1985-31/12/2014	DGO2
Sambre	Solre/Sambre	1188	F11SAM7487	1/01/1998-31/12/2015	DGO2
Sambre	**Salzinne Ronet**	**2669**	**W11SAM7319**	**1/07/2006-31/12/2014**	**DGO2**
Berwijn	**Moelingen/Berwijn**	**128**	**W11BER551010**	**1/01/1991-31/12/2014**	**VMM**
Jeker	**Kanne/Jeker**	**465,5**	**W11JEK553010**	**1/01/1993-31/12/2014**	**VMM**

Figure 2 (p.4) gives a synthetic view of the main tributaries catchments and gauging stations on the Meuse upstream Maastricht. All stations of Table 1 are represented. In addition, the figure shows Amay and Visé gauging stations (controls) and a few strategic locations with water height measurements : Dinant, Profondeville and Grands-Malades.

Figure 1 – Map of gauged and ungauged subcatchments of the Meuse basin in Belgium

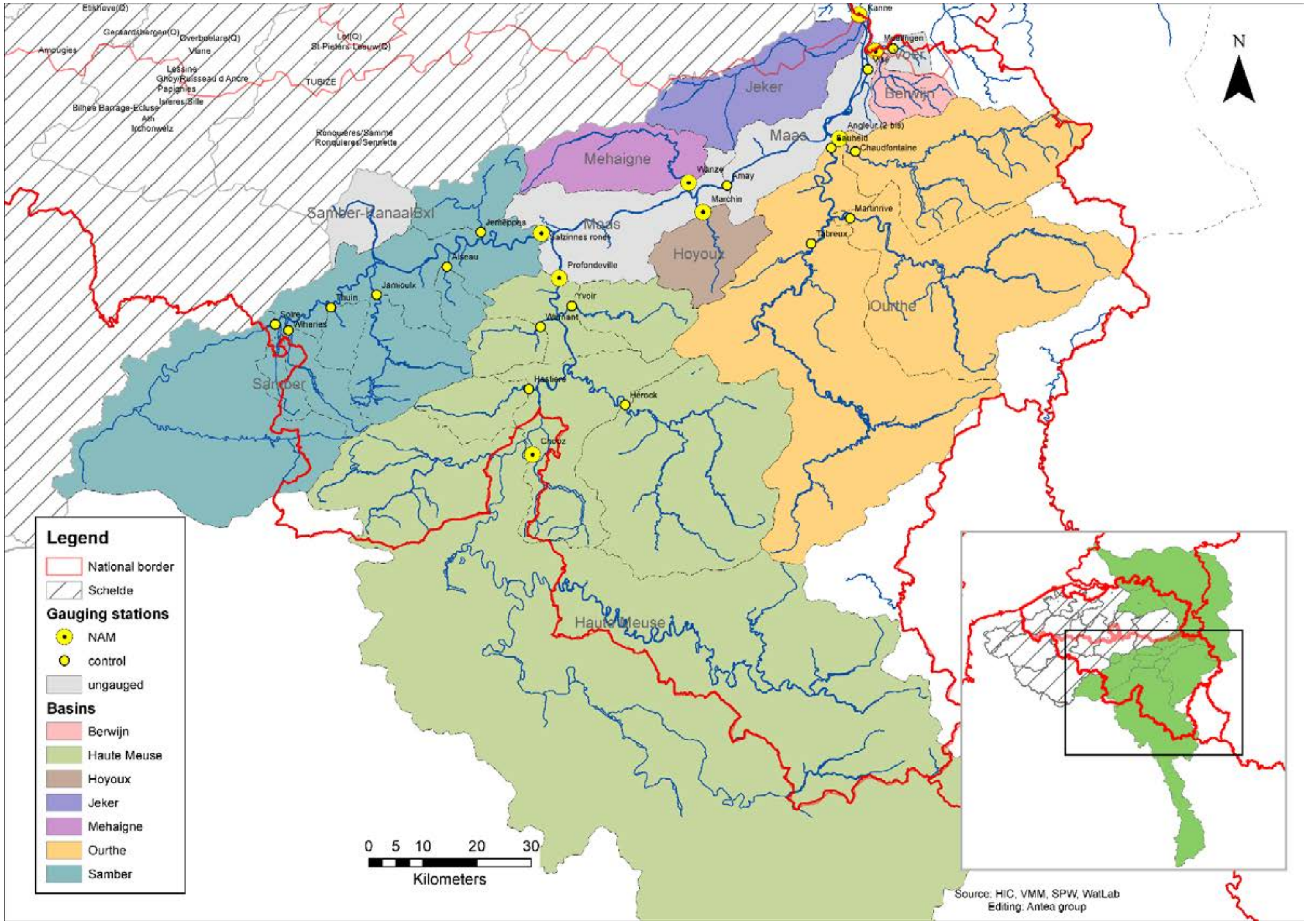
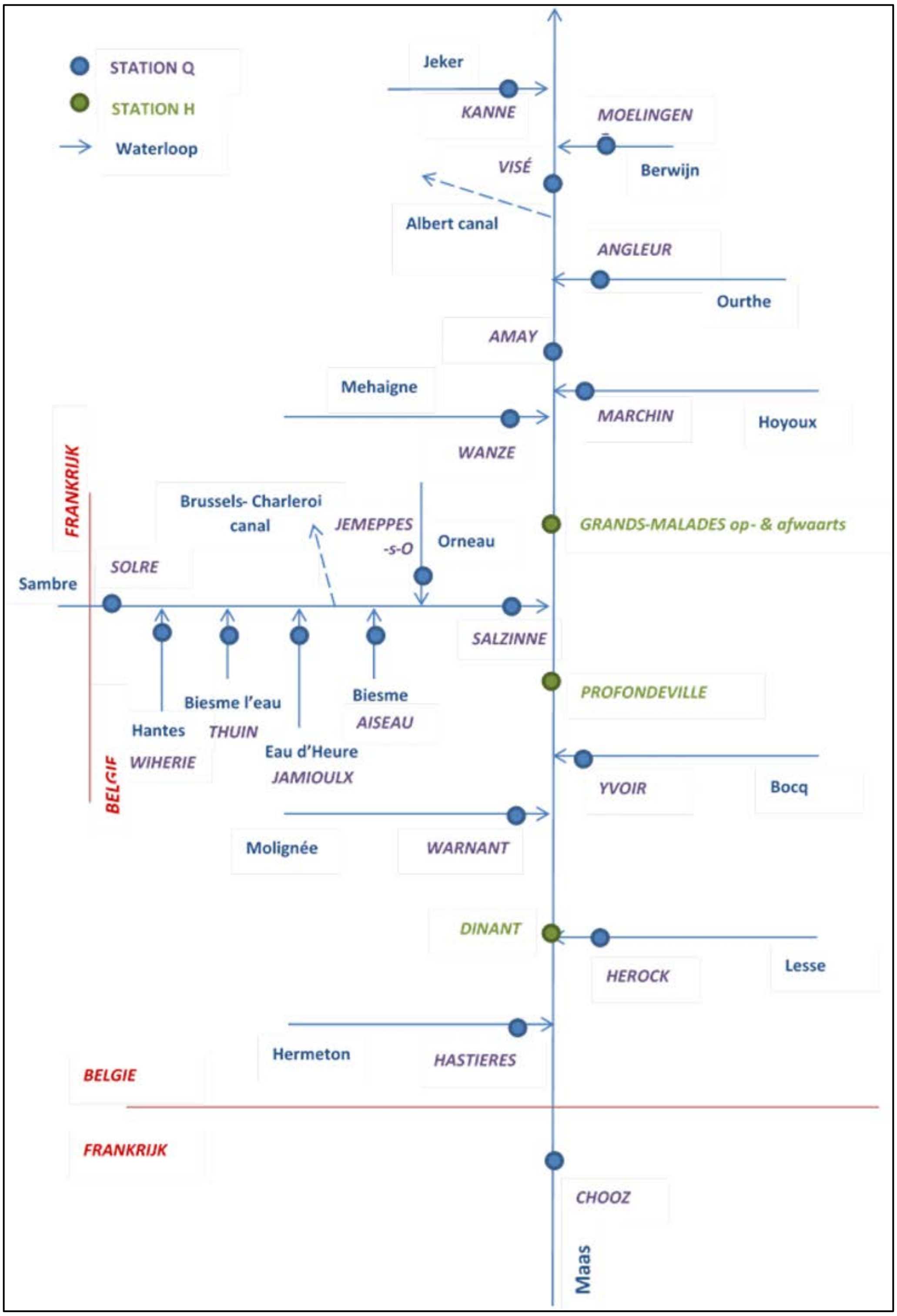


Figure 2 – Schematic view of the Meuse basin



Remarks:

- "Angleur 2 bis" is no actual gauging station but discharge is calculated in that location by the SPW (DGO2) based on measurements in Sauheid on the Ourthe and Chaudfontaine on the Vesder.
- For Salzinne, the most reliable time period for flow measurements is from July 2006 when the DGO2 installed a ultrasound flowmeter.

2.2 Selection of gauging stations for calibration

A rational selection of some of the stations listed in the previous section were used for calibration of the NAM models. For efficiency purposes, NAM models were limited to a minimum of subcatchments. However, there are withdrawals along the course of the Meuse that make it difficult to find a simple and unique rainfall-runoff relationship for the lower parts of the basin. Only when catchments have a regime close to a *natural* situation, i.e. when withdrawals and human influence are negligible or evened out when looking at total outflow, rainfall-runoff models will perform well. To be able to realistically calibrate such models, the catchment also needs to be physically homogeneous to allow a lumped treatment.

Because of the large working scale, and because of limited access to data about Walloon water management, quite large subcatchments were selected to model the Meuse basin (Table 2). Depending on availability of reliable data, calibration periods of about 8 to 13 years were selected in the most recent years, between 2001 and 2014. Such long calibratioin periods were possible thanks to the model fast computation time. Validation was performed on the whole period with discharge measurements.

Table 2 – Final list of flow measuring stations for the calibration of rain-runoff model parameters in the Meuse basin

Basin	**Station/River**	**Station number**	**Area (km²) delineation**	**Subcatchment ID**	**Calibration period**
Hoyoux	Marchin/Hoyoux	5990	242	W11HOY5990	1/01/2001-31/12/2013
Mehaigne	Wanze/Mehaigne	5820	356	W11MEH5820	1/01/2004-31/12/2013
“Haute Meuse” (Meuse upstr. from Profondeville)	Profondeville/Meuse	calculated	12586	W11MAAPROF	1/01/2002-31/12/2013
“French Meuse” (Meuse upstr. Chooz)	Chooz/Meuse	8702	10120	F11MAA8702	1/01/2002-31/12/2013
Ourthe	Angleur 2 bis/Ourthe (calculated)	5805	3612	W11OUR5805	1/01/2001-31/12/2013
Sambre	Salzinne Ronet/Sambre	7319	2669[1]	W11SAM7319	1/07/2006-31/12/2014
Berwijn	Moelingen	551	128	W11BER551010	1/01/1994-31/12/2006
Jeker	Kanne	553	465,5	W11JEK553010	1/01/1993-31/12/1998

The station in Amay was used as control. Visé is located downstream of the Albert canal junction with the Meuse, where part of the discharge is known to flow out of the system. Therefore, it cannot be used as control.

To give an idea of relative importance of each tributary, Table 3 below gives some flow statistics for Amay and Visé in comparison with the main contributors on the basin. The minimum discharge in Visé is surprisingly low (1,46 m^3/s) when compared upstream Amay (19,24 m^3/s). This comes from the fact that water is diverted from the Meuse into the Albert canal (object of the water allocation model update for the Meuse, see DO1). While this has little effects in normal and wet conditions, this diversion is far from negligible in times of low flows.

[1] Surface area draining to the canal Brussels-Charleroi is excluded from the Sambre and Amay catchment.

Table 3 – Surface area and statistics on flow for the Meuse and the Sambre (source: SPW/DGO2)

Station	River	Catchment surface area (km²)	Reference period	Q Min (m³/s)	Q Max (m³/s)	Q Avg (m³/s)
Salzinnes Ronet	Sambre	2669[1]	2007 - 2015	3,01	272,23	26,55
Chooz	Meuse	10120	1990 - 2014	11,80	1512,57	147,47
Amay	Meuse	16243[1]	1996 - 2012	19,24	1792,67	206,64
Sauheid	Ourthe	2915	1987 - 2015	1,79	607,50	44,50
Visé	Meuse	20450	1996 - 2015	1,46	2323,16	227,88

2.3 Consistency of hydrographs

In this section, we assess the consistency of hydrographs for the modelled catchments selected above, and we discuss the issues that could disturb measured discharge time series as to make them difficult to use for lumped modelling.

All discharge data is provided by the SPW[2], except for the stations of Kanne and Moelingen where discharge data is provided by the Vlaamse Milieu Maatschappij (VMM) and validated by the Waterbouwkundig Laboratorium (WL).

2.3.1 Meuse upstream from Profondeville (Haute Meuse)

In this paragraph, we want to show that it is reasonable to model the upper part of the Meuse catchment (upstream from Profondeville) as one lumped model and we discuss the calibration and validation methodology for the different subcatchments upstream Profondeville.

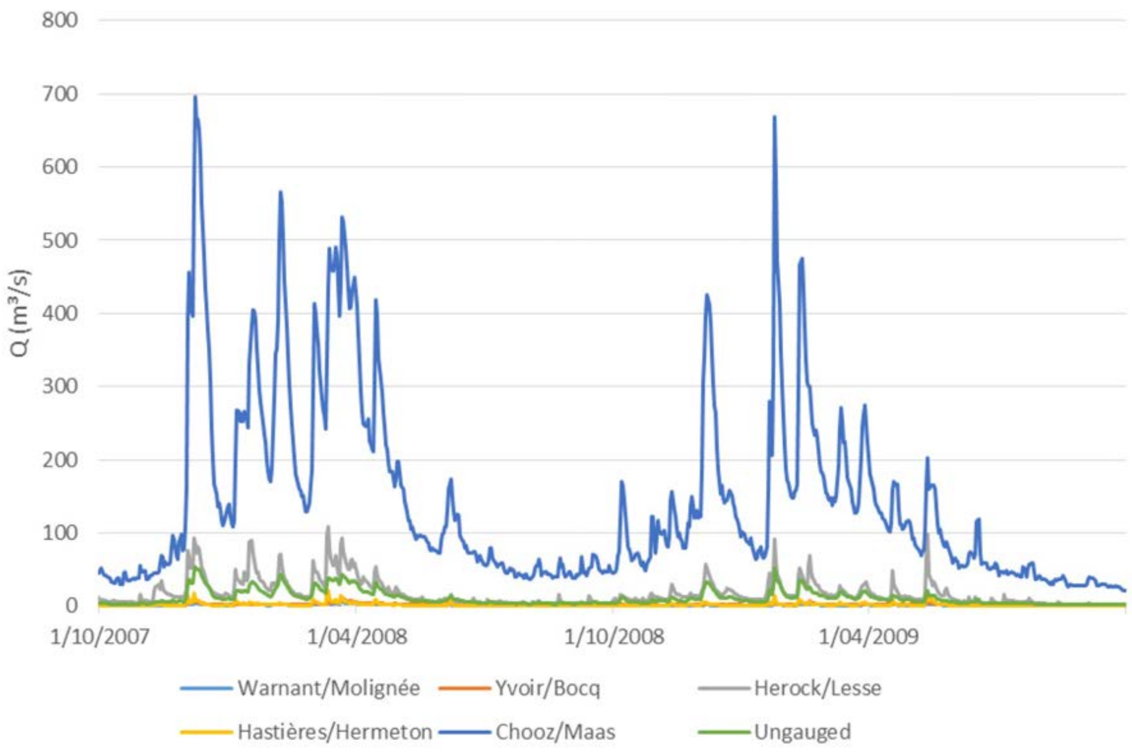
The Meuse upstream Profondeville includes 5 gauged subcatchments: Chooz (Meuse), Warnant (Molignée), Yvoir (Bocq), Hérock (Lesse) and Hastière (Hermeton) (Table 4). 6,2 % of the catchment upstream from Profondeville remain ungauged.

Table 4 – Surface area of the Meuse subcatchments upstream from Profondeville

	Profondeville	Warnant	Yvoir	Herock	Hastières	Chooz	Gauged	Ungauged
Surface area (km²)	12585	124	230	1159	169	10132	11814	771
%	100%	1,0%	1,8%	9,2%	1,3%	80,5%	**93,8%**	**6,2%**

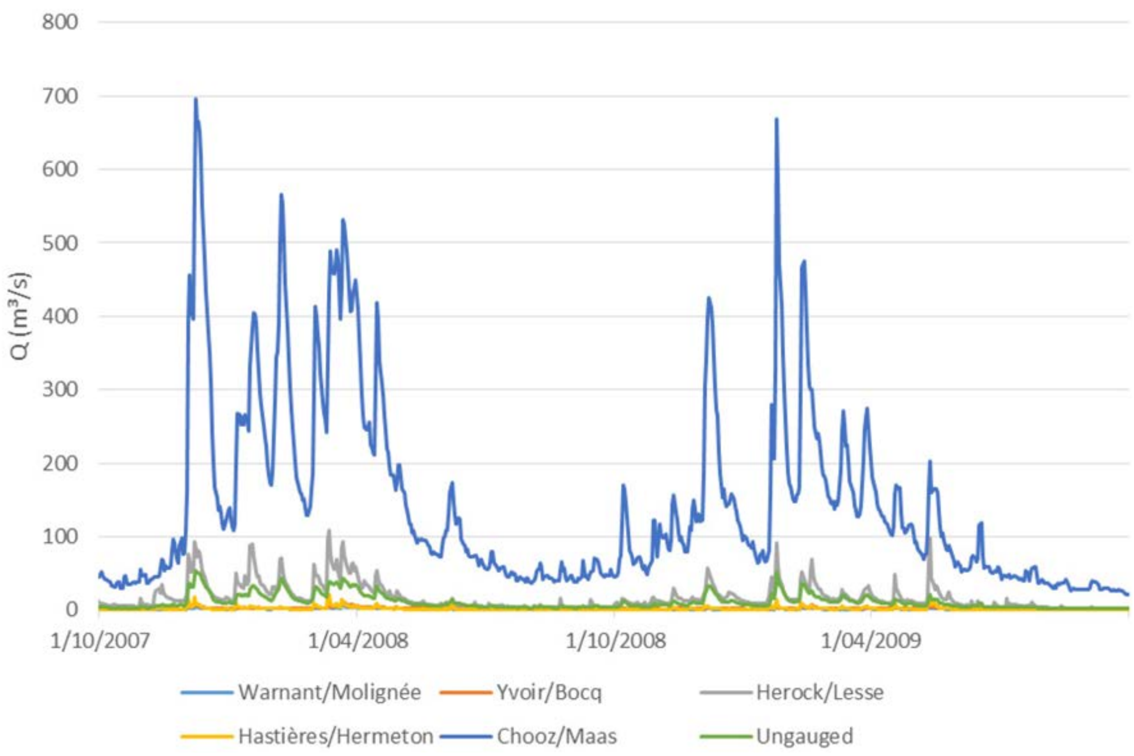
[2] Service Public de Wallonie, Direction générale opérationnelle de la Mobilité et des Voies hydrauliques DGO2 and Direction des Cours d'Eau non navigables of DGO3 (Département de la Ruralité et des Cours d'Eau au sein de la Direction générale opérationnelle Agriculture, Environnement et Ressources naturelles (DGARNE))

Figure 3 – Measured discharge in Chooz (Meuse), Warnant (Molignée), Yvoir (Bocq), Hérock (Lesse), Hastière (Hermeton)



Chooz is the main contributor and is located at the French border. The Bocq, the Molignée and the Hermeton are very small contributors in terms of surface area (Table 4) and in terms of discharge (barely visible on xxx

Figure 3 – The "ungauged" time series is reconstructed proportionally to the surface area.



In order to accurately know the situation at the French border, it is essential to have the best model possible to simulate the runoff in Chooz. Therefore, we first calibrated and validated a model based on the Chooz discharge time series.

No major change or disturbance are expected between Chooz and Profondeville, so we chose to proceed to the valibration at the scale of the catchment upstream from Profondeville, as one lumped catchment. Profondeville is practical choice located right upstream from a major surface water uptake in Tailfer. There are no discharge measurements in Profondeville. Therefore, a constructed time series had to be used, calculated based on measured discharge at the five upstream tributaries stations. In order to check model robustness, the same parameter values were also validated for each of the contributing subcatchments separately, by comparing simulated and measured discharge. However, model error for each of the smaller tributaries should have only limited impact on the situation in Monsin.

In summary, the NAM parameters values were calibrated based on the Chooz time series and then transferred to the rest of the catchment upstream Profondeville: for each subcatchment individually and as one lumped model for Profondeville. While the same parameters are used everywhere, rainfall and evaporation inputs were averaged separately for each catchment.

2.3.2 Sambre

The physical characteristics of the Sambre catchment are relatively homogeneous. Therefore, it is realistic to model it as one lumped catchment. Two infrastructures might however disturb the consistency of the flow data: the reservoir complex of L'Eau d'Heure and the canal Brussels-Charleroi.

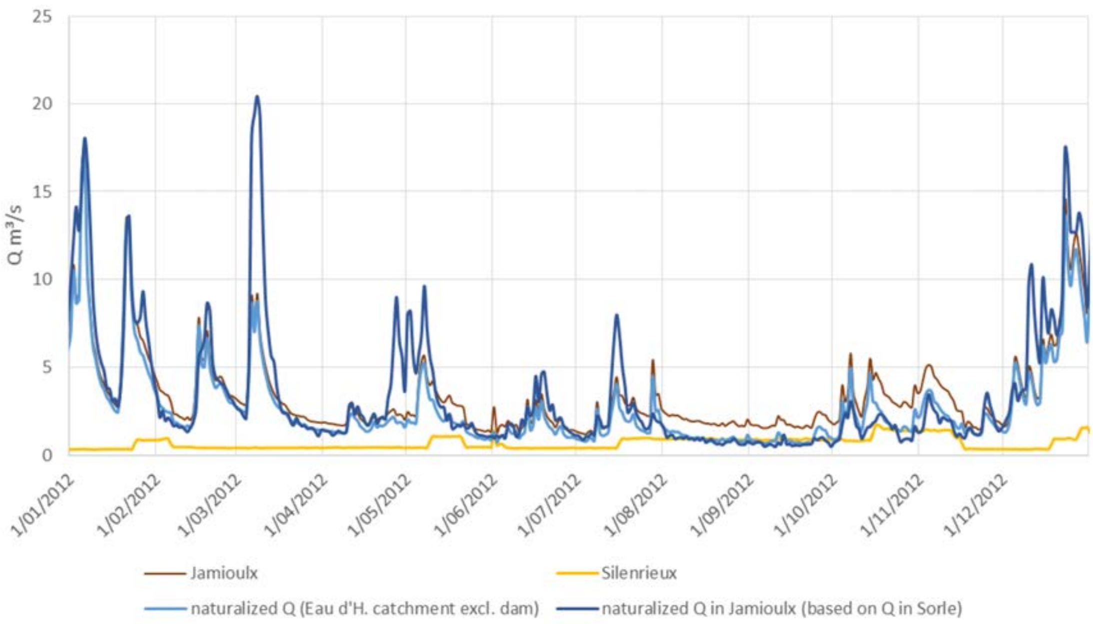
Reservoir complex of L'Eau d'Heure

L'Eau d'Heure is a tributary of the Sambre. The discharge in this catchment is partially determined by the reservoir complex of L'Eau d'Heure. The main tributaries of the dams are the Thyria and the Ry d'Yves. The discharge of l'Eau d'Heure is measured in Jamioulx, about 8 km upstream from the confluence with the Sambre (catchment of 322 km²). An additional gauging station is located in Silenrieux, directly downstream from the dams (catchment of 78 km²).

On Figure 4, two "naturalized" flows are compared to observed discharge in Jamioulx. These naturalized flow are attempts to reconstruct the natural behavior of the L'Eau d'Heure river, unaffected by the dams. Because of the uncertainty associated to these calculations, two different approaches are used. First, this naturalized flow is calculated as a proportion of the discharge measured in Solre, proportionnaly to the surface area (in dark blue on Figure 4). Second, a naturalized flow time series (light blue) is calculated as the difference between observed discharge in Jamioulx and discharge measured right downstream from the dams, in Silenrieux. During low flows, these two naturalized time series match. In times of recession, naturalized Q is systematically lower than measured discharge in Jamioulx, in particular in August and September 2012 on Figure 4. This shows that the dams play a flow supporting role during dry periods.

Regarding the dams influence on high peaks, Figure 4 shows that, when higher peaks take place on the rest of the catchment (dark blue), discharge in Jamioulx does not always reflect similar peaks (brown). This is a logical consequence of water being stored in the reservoirs in times of high flows. This is of little concern in the framework of this water availability study, as we are focusing on low flows.

Figure 4 – Measured and naturalized discharge in Jamioulx in 2012



This analysis shows that the L'Eau d'Heure complex disturbs slightly the flow regime in Jamioulx, including during dryer periods. However, these supporting spills from L'Eau d'Heure should not, however, affect greatly the discharge downstream of the Sambre, in Salzinne, as it is in fact dedicated to supplying the Brussel-Charleroi canal.

Canal Brussels-Charleroi

According to an analysis by IMDC (2008), a discharge of about 3,5 m³/s should be guaranteed in the Brussels-Charleroi canal in Marcinelle to maintain water levels that are sufficient for navigation in the reach of Partage. In times of low flows, this minimum discharge is normally provided by the outflow from the reservoirs of L'Eau d'Heure, in order to prevent an additional decrease of the discharge of the Sambre downstream.

The actual management regime of the canal of Brussells-Charleroi is not known with precision. In normal conditions, water is pumped from the Sambre into the canal. Water from the Piéton and other small natural tributaries of the Sambre are also flowing into the canal, thus reducing the effective surface area of the Sambre catchment (see map p.3). An estimated surface area of 173,1 km² of the natural catchment of the Sambre is in general draining into the canal (source: IMDC 2008). During peak flows however, water is flushed out to the Sambre through spillways.

IMDC calculated an average water deficit of 17m³/h (=0,005 m³/s) in Marchienne over the year 2003. This average deficit is close to zero over the year but accounts for both pumping from the Samber during dryer periods, consumption and losses for sluice operation and spilling during high peaks. At a daily timescale, deficit and pumping can be non-negligible with an estimated deficit of about 4200 m³/h (1,16 m³/s) in 2003. Most of the time (i.e. when the dams are managed adequately), this deficit is compensated for the most part by the supporting flow of the l'Eau d'Heure complex and the rest was returned to the Samber via lock consumption, leading therefore to a quasi null annual average balance.

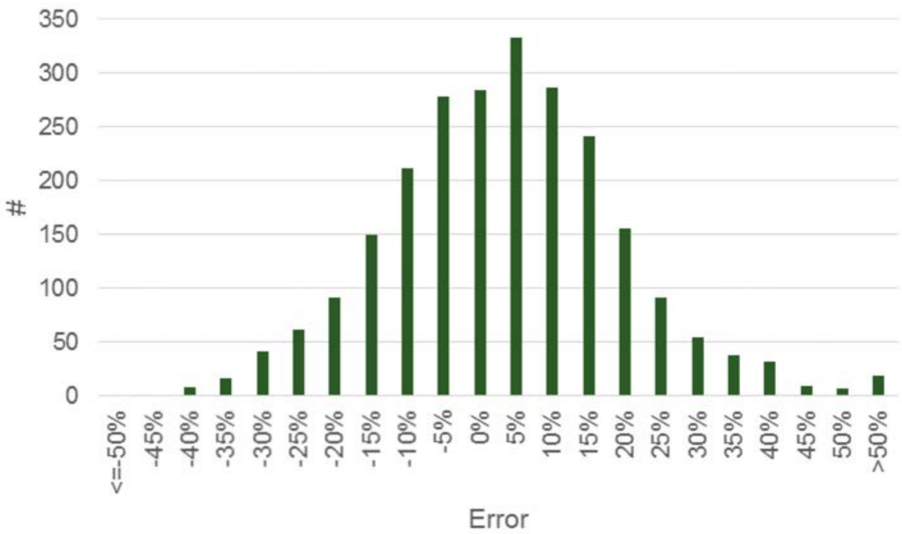
Because the compensation between canal pumping and l'Eau d'Heure spills is not perfect over the years, we are likely to find some discrepencies between measured daily flows in Salzinne and expected flow deduced from the upstream measurements. To assess these discrepancies, we look at the error distribution between "natural" and "altered" discharge in the Samber. To approximate "natural" flow, we consider the sum of discharge values from the 6 upstream gauging stations, with a corrective factor according to surface area the remaining ungauged zones.

Because interactions of this system are unkown, not linear (e.g. more pumping during low flows, spills during peaks) and probably inconsistent (dam and pomp management), we do not expect any linearity of the error. With this in mind, the error between discharge measurements in Salzinne and the corrected sum of discharges measured in the 6 upstream stations is calculated as follow:

$$\varepsilon = \left(\sum_{i=1}^{6} Q_i - Q_{Salzinne}\right) / Q_{Salzinne} \qquad \text{Eq. 1}$$

The error distribution is shown at Figure 5. The average error is equal to 1,1 % and the median is 0,8 %. This slight overestimation appears small enough to be able to model the Sambre catchment based on the discharge measured in Salzinne.

Figure 5 – Error distribution for flow in Salzinne
(corrected sum of discharges in upstream subcatchments vs measurements in Salzinne)



Conclusions for modelling the Sambre

Because the flow coming from L'Eau d'Heure in times of low flow is generally directly aiming at providing enough water for the canal without impacting discharge in the Sambre, we make the assumption that the influence of these two human disturbances (reservoirs and canal pumping) balance each other out for low flows. If this is true, the dynamics of the discharge in the Sambre can be modelled as lumped, ignoring both processes.

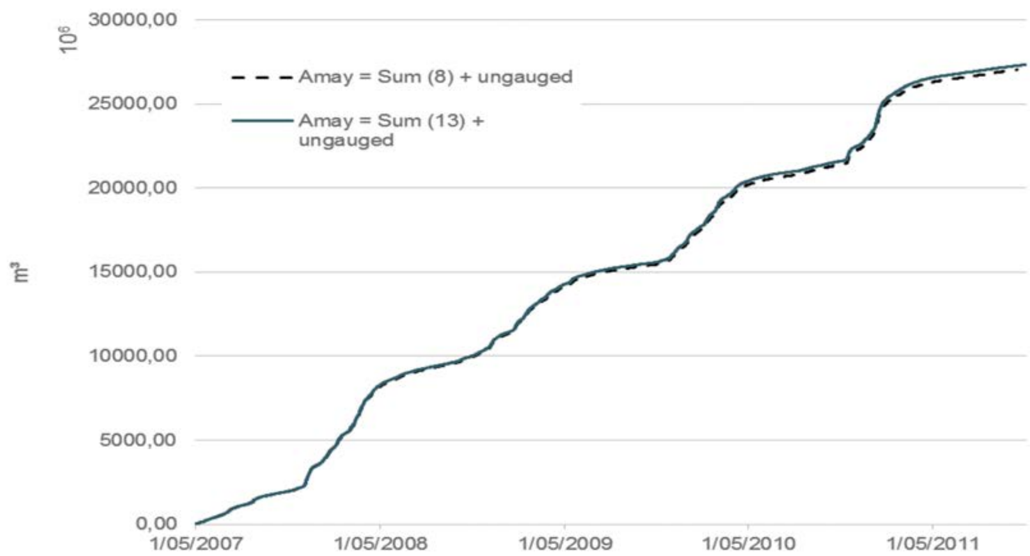
We will therefore calibrate the rainfall-runoff model for the Samber using discharge measurements in Salzinne. Doing so, we integrate inside the model the possible influence of the infrastructure described above. Still, a portion of the natural catchment of the Samber is contributing directly to the canal during dry periods. Therefore, the surface area of the lumped model was diminished accordingly.

However, it is likely that there will be an error in the water balance during wetter periods. Indeed, on the one hand, during filling phases of the reservoirs, measured flow in Jamioulx is less than expected when reservoirs are being recharged. On the other hand, at the scale of the Sambre, excess of water is flowing through spillways from the Piéton and other tributaries of the canal into the Sambre, producing higher flow peaks than expected. We discard these processes for the present study because we focus on low flow.

Even if we ignore them at this stage, the two human disturbances mentioned in this section should be kept in mind in the next steps of the project, for climate change projections, as they might be a limitation to rainfall-runoff modelling.

At the scale of the Meuse basin however, the average discharge of the Sambre represents only about 1/10 of the average flow in Monsin and Visé and any error on the Sambre should influence only marginally results in Monsin (Table 3). There are no discharge measurements in Monsin but Figure 6 shows the difference of balance in Amay when using Salzinne measurements (discontinued) or upstream stations (continued). There is no significant difference between the two time series. This increases confidence for using Salzinne as reference gauging station for the Samber.

Figure 6 – Cumulative discharge in Amay according to Salzinne station measurements or to upstream stations



2.3.3 Meuse upstream from Amay

To assess consistency of the discharge data along the Meuse, Figure 7 gives a sight of total flow in 2008 at different control points: Amay, Profondeville, Chooz and Salzinne.

Figure 7 – Measured discharges in Amay, Chooz and Salzinne and reconstructed discharge in Amay and Profondeville based on respectively 8 and 5 upstream gauging stations (October 2007 to September 2008)

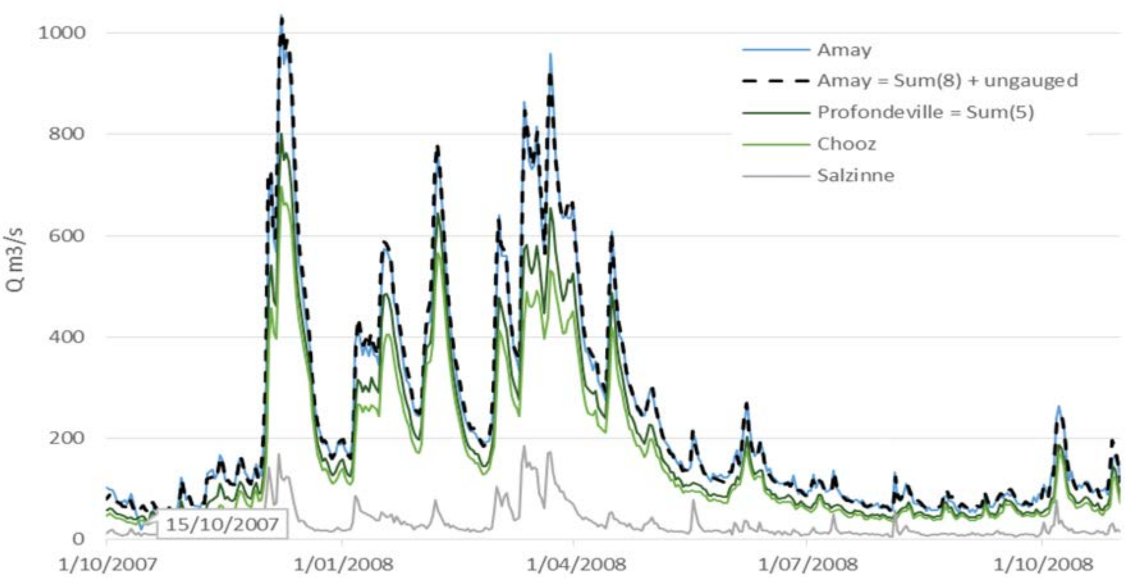
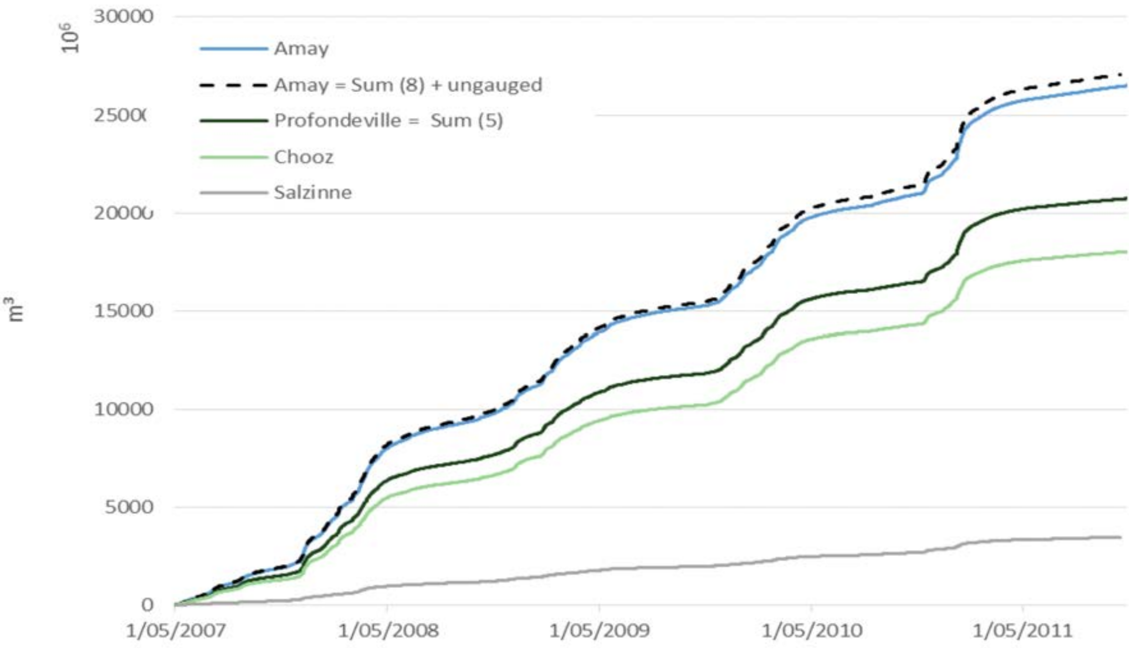


Figure 8 – Cumulative flow in Amay, Chooz and Salzinne and reconstructed discharge in Amay based on 8 upstream gauging stations (May 2007 to October 2011)



Measured data in Amay (blue) is very consistent with the expected discharge, calculated as the corrected sum of discharge values measured upstream, in Salzinne, Chooz, Warnant, Yvoir, Herock, Hastières, Wanze and Marchin stations (discontinued black). Good agreement between expected and measured discharge in Amay increase our confidence in the choice of Profondeville and Salzinne as reference stations for the hydrological models.

Despite good agreement, there is a slight overestimation discharge in Amay (continuous blue). This may be due to intensive surface water extraction in Tailfer, close to Profondeville. This is the biggest pumping site of Vivaqua, with a maximum pumping rate of 260.000 m³/day and a long term capacity of 180.000 m³/day i.e. 2,1 m³/s (source: Vivaqua). In the SPW Dix-sous database, Tailfer has an average production of 48 million m³/year, i.e. 1,5 m³/s (source: SPW/DGARNE Dix-sous database). These estimates represent 0,7 to 1 % of the average discharge in Amay (206,6 m³/s). Taifer is therefore a likely explanation for the slight overestimation observed at Figure 7 and Figure 8. Note however that this error remains low and below the uncertainty associated with calibration of the rainfall-runoff models.

2.3.4 Ourthe

There are several major reservoirs on the Ourthe (Nisramont), the Vesdre (Eupen and Gileppe) and the Amblève (Robertville and Butgenbach). The dams, as well as the Hautes Fagnes peatlands, are probably responsible for the difference of response between the Ourthe in Tabreux and the rest of the catchment (Vesdre and Amblève). However, their influence is not explicitly taken into account at this stage of the modelling process as they are implicitly included into the lumped model of the Ourthe.

Figure 9 and Figure 10 show cumulated flow and total flow in Angleur as given by the SPW dataset, consisting of calculated values based on Sauheid and Chaudfontaine. These are compared to the sum of measured discharge in Tabreux, Chaudfontaine and Martinrive (with a correction for the ungauged area). From these figures, the Angleur time series seems suited for calibrating the model of the Ourthe. The influence of the dams was therefore implicitely modelled by the consequently calibrated NAM model.

Figure 9 – Annual cumulative flow of the Ourthe as measured in Angleur and as the sum of measured flow in Chaudfontaine, Martinrive and Tabreux (corrected for ungauged zone according to surface area)

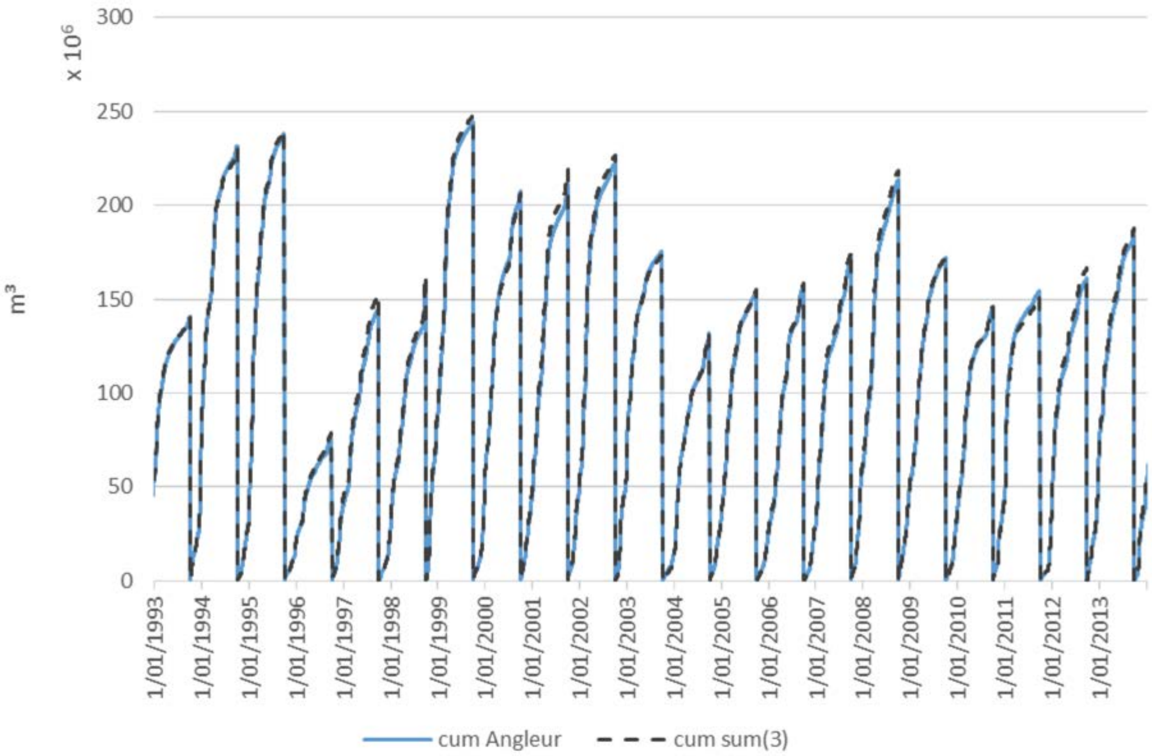
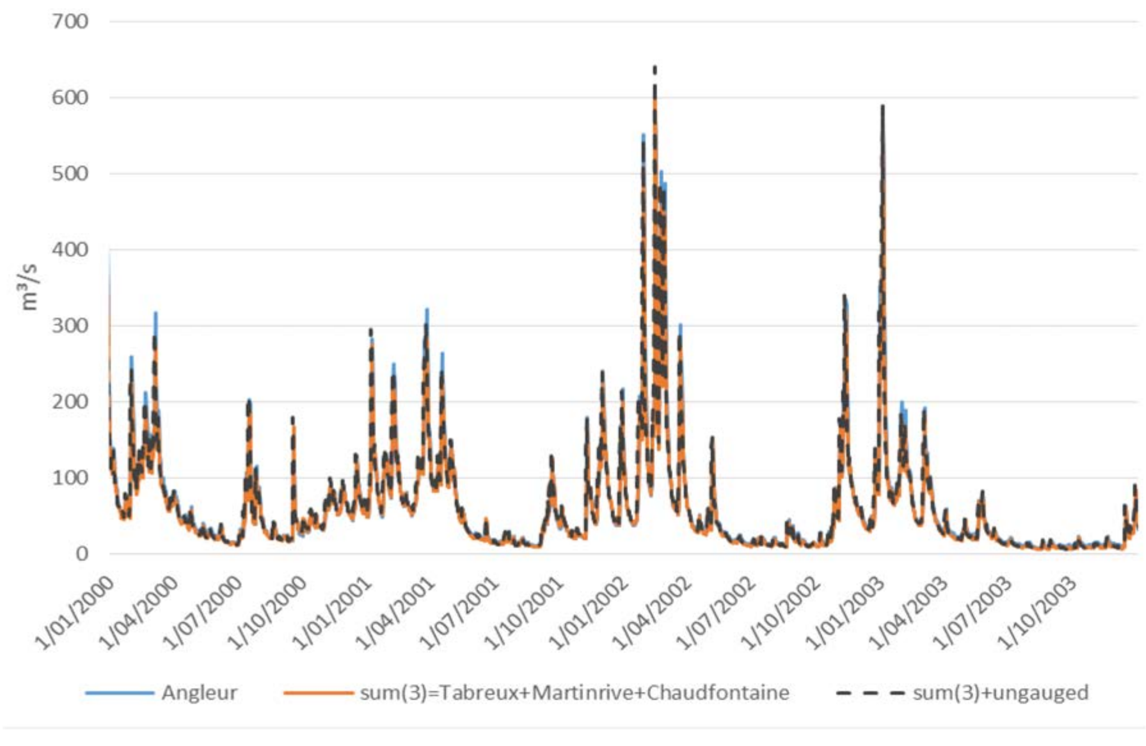


Figure 10 – Total flow of the Ourthe as measured in Angleur and as the sum of measured flow in Chaudfontaine, Martinrive and Tabreux (with and without correction for ungauged zone according to surface area)



3 Input data Pre-processing

3.1 Thiessen polygon method

Just like for the Scheldt basin, interpolated precipitation was produced for each catchment according to the Thiessen polygon method, using the Hydr@ modules developed by IMDC (2010). Rainfall and evapotranspiration are interpolated using weights inversely proportional to the distance to the weather station, using measurements available for each time step. Because of the long term nature of this study, daily data was used.

3.2 Precipitation

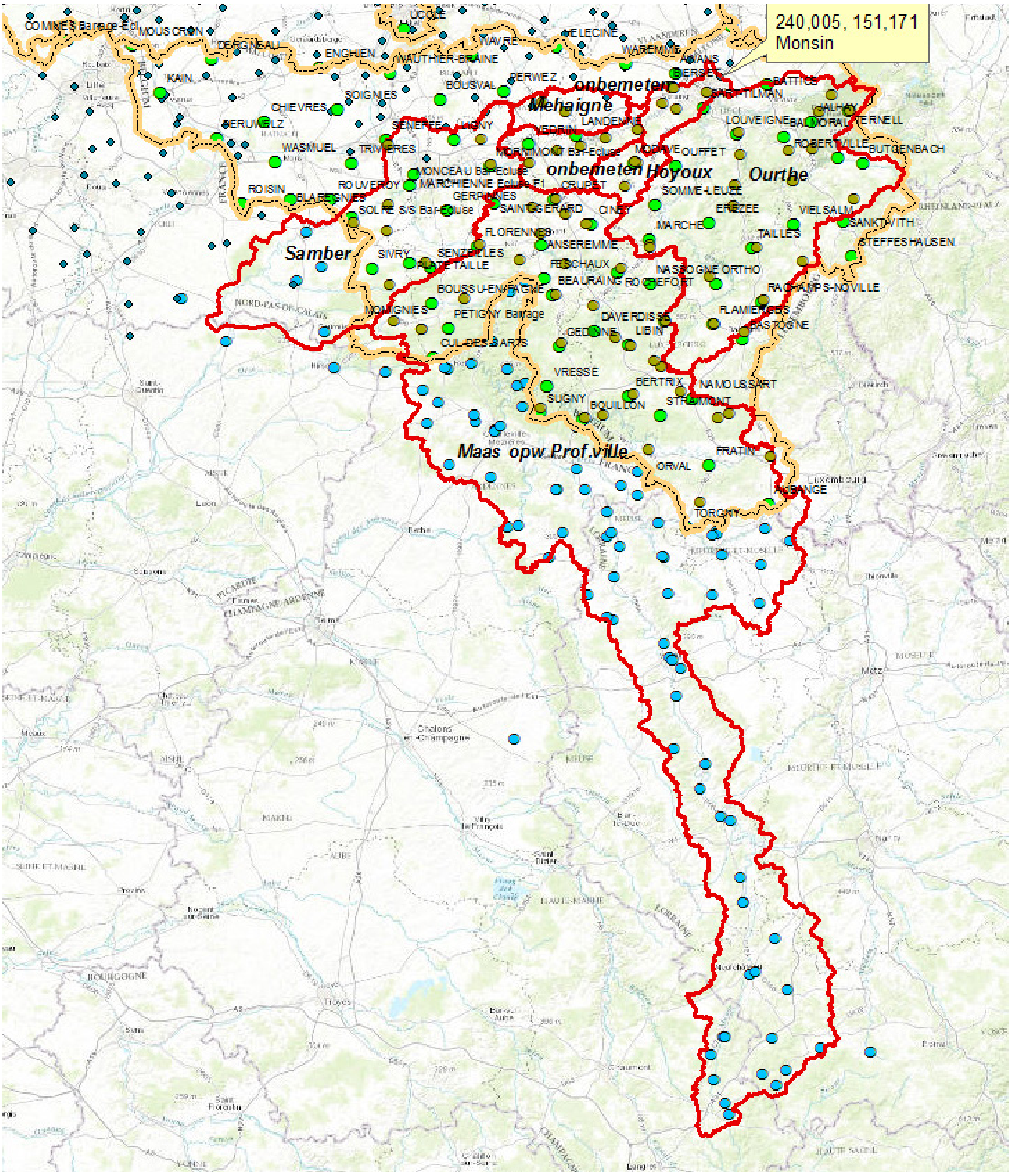
3.2.1 Pluviographs

For the production of NAM discharge for the Meuse catchment up to Visé, Thiessen precipitation needed to be calculated for all chosen basins (Section 2.2). Source data consisted of pluviographs measurements from 1967 to 2013, spread over the entire Meuse catchment and also some pluviometers that are close to the catchment.

The Meuse catchment under study extends over Wallonia and France (and a small corner in Luxembourg). Precipitation data was thus gathered from instances in Belgium and France. For Belgium, precipitation data was gathered from KMI (The Royal Meteorological institute) and SPW (Public Services of Wallonia). For France, data was gathered from Météo France.

Figure 11 shows a map of used rainfall metering stations on and around the Meuse basin (Météo France in blue, SPW/DGO2 in bright green (2002-2014 only) and KMI as larger and smaller green dots).

Figure 11 – Map of rainfall the measuring stations on and around the Meuse basin
(Météo France in blue, SPW/DGO2 in bright green (2002-2014 only) and KMI (larger and smaller green dots)



3.2.2 Interpolated rainfall

Results of interpolated rainfall are presented on Figure 12. The wettest catchment is the Ourthe, with average annual rainfall of 1053 mm. The second wettest catchment is the upper part of the Meuse basin with 977 mm per year. The Jeker is the driest catchment with 771 mm annually on average. These contrasts can easily be explained by the higher relief on the Ourthe catchment and the typically wetter Ardenne climate, south of the Samber-Meuse channel (Figure 13). A table of annual total and average precipitation per catchment is given in the Annex 1.

Figure 12 – Precipitation interpolated for all catchments of the Meuse

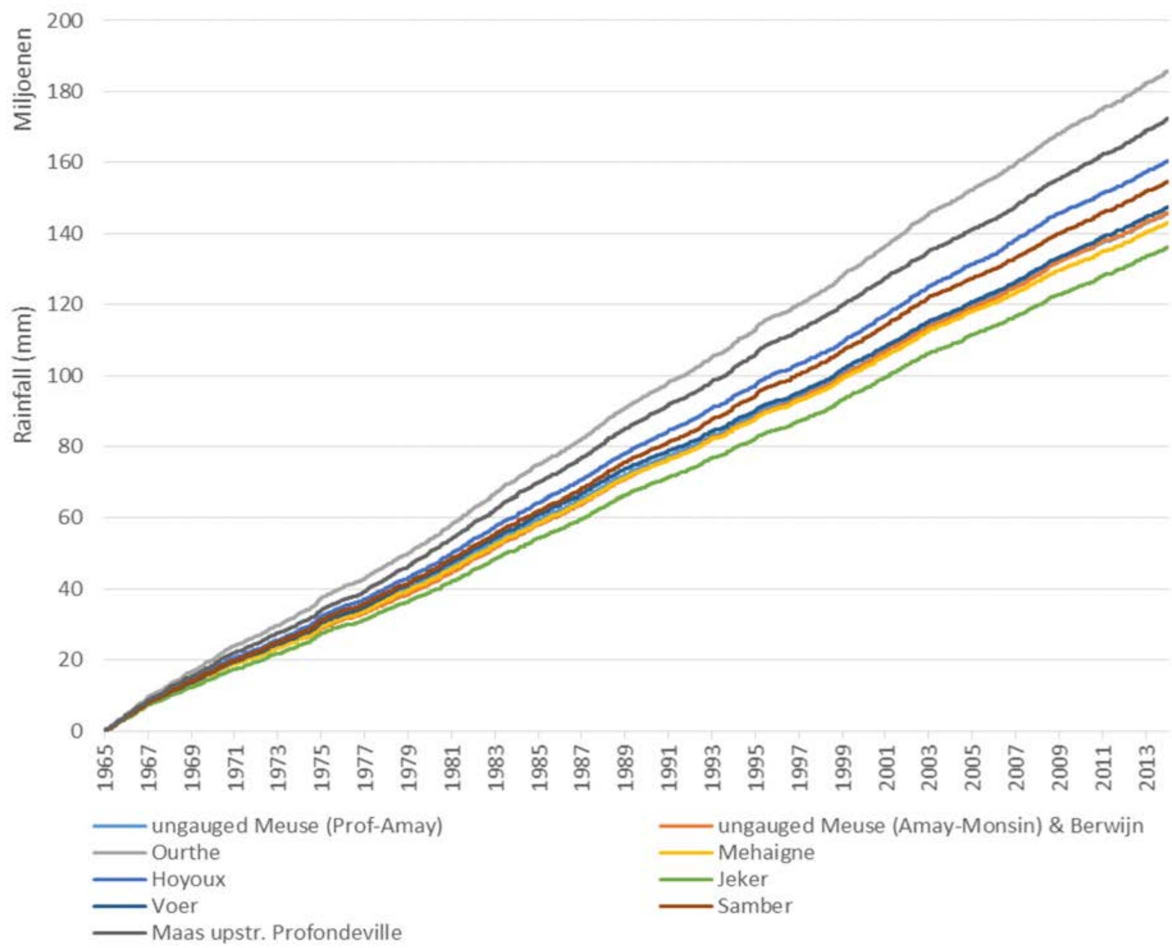


Figure 13 – Annual average precipitation in Belgium : climate normal values for 1981 – 2010 (source: KMI)

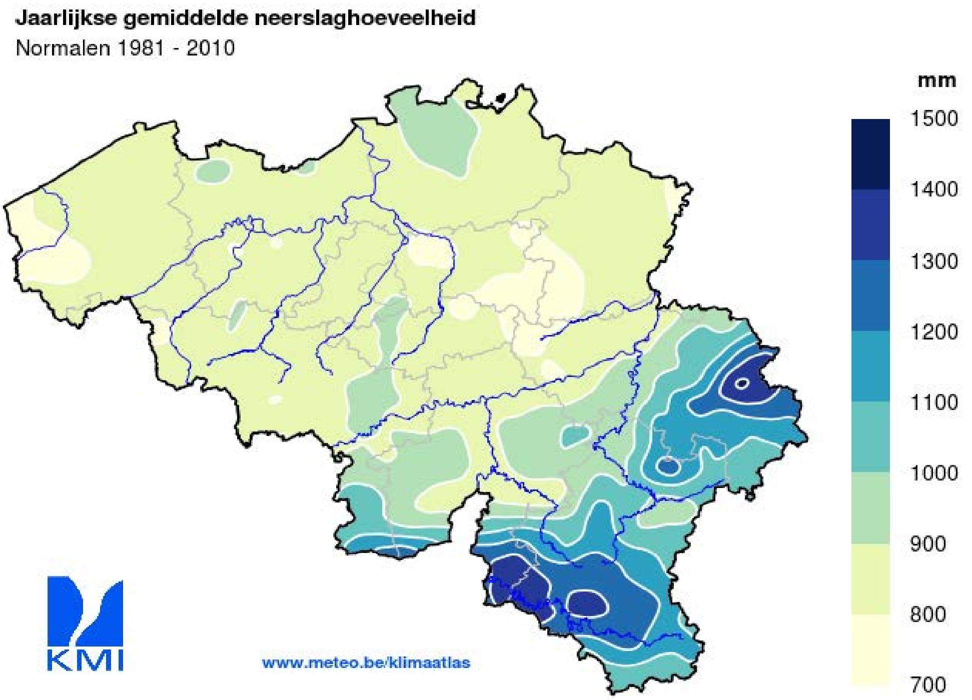
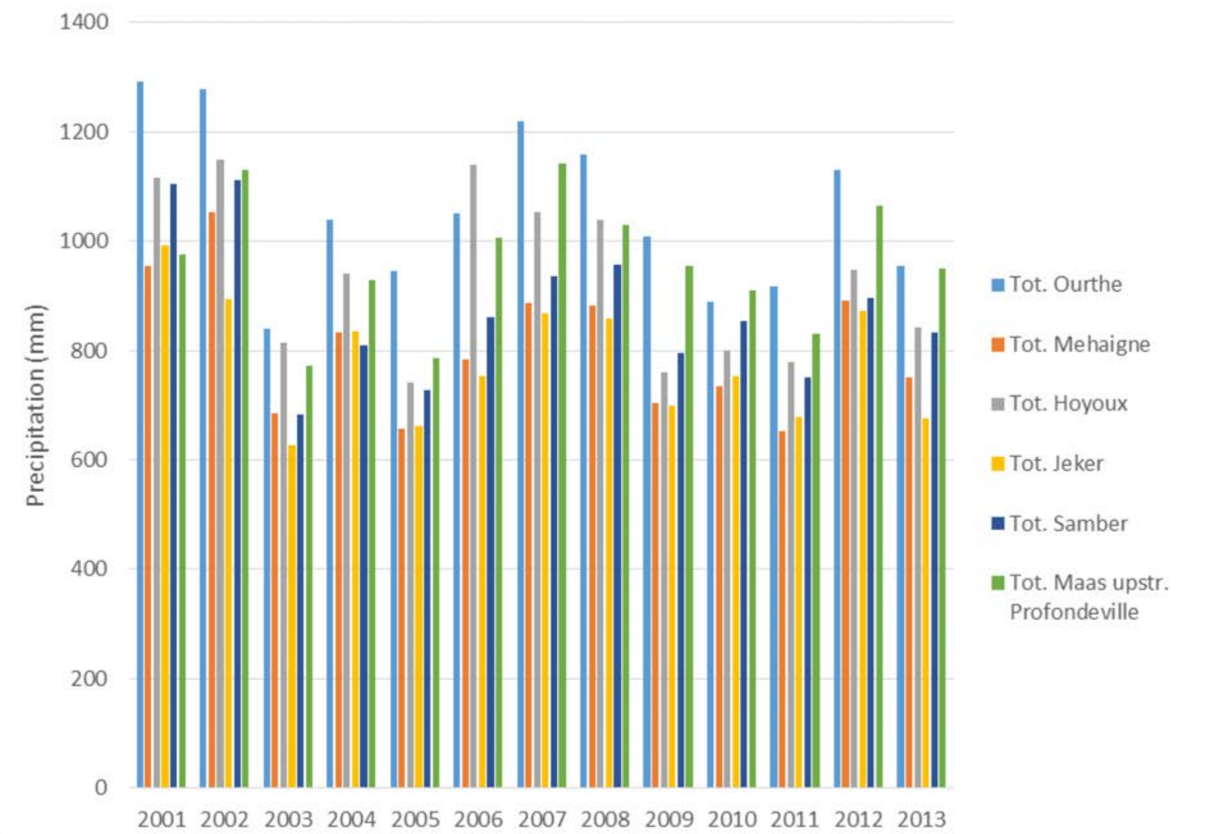


Figure 14 – Annual precipitation over the main catchments of the Meuse basin (2001-2013)



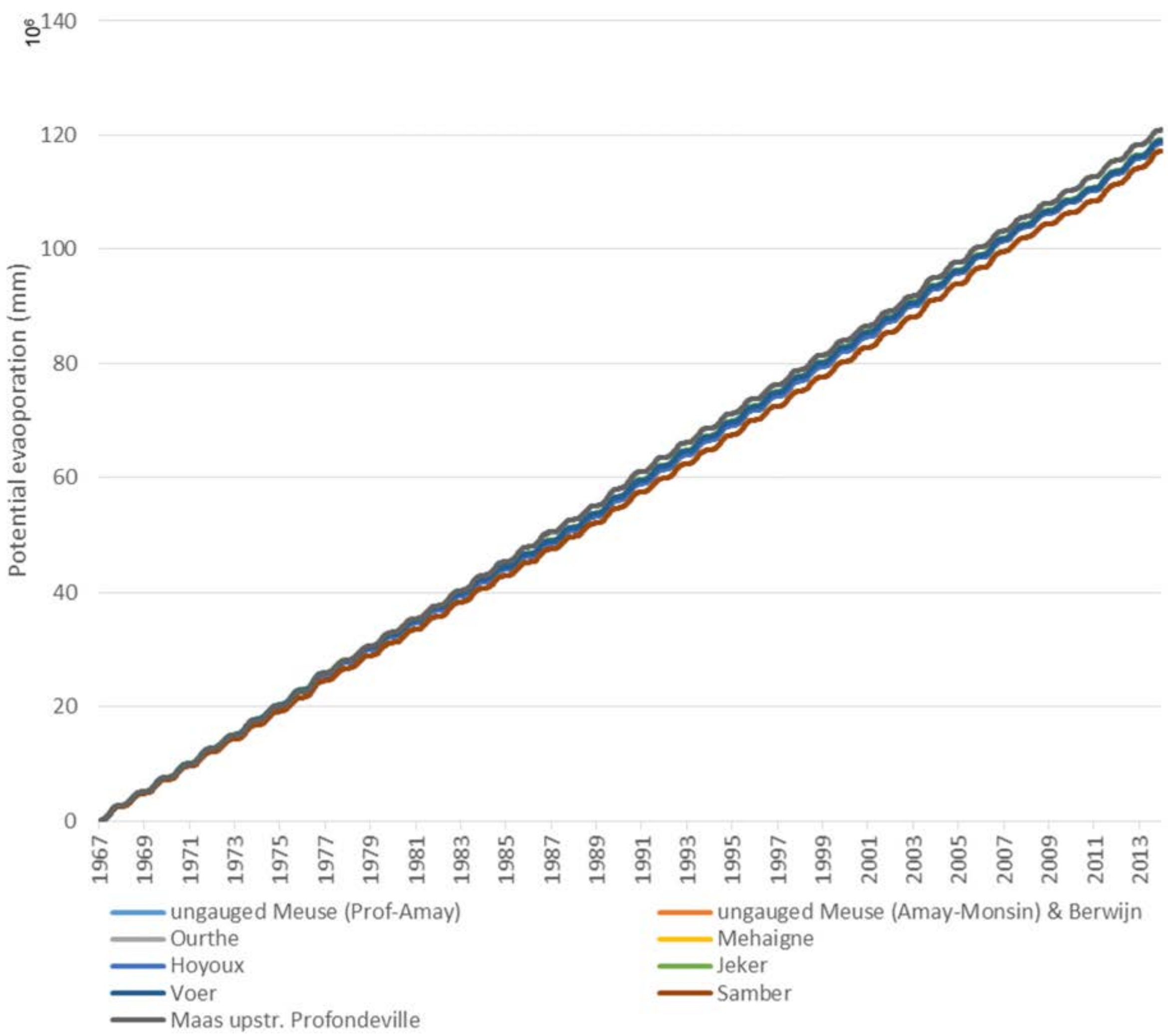
3.3 Evapotranspiration

3.3.1 Measuring stations

Whereas there is a lot of precipitation input data, it doesn't apply for evaporation data. Evaporation measurements were very scarce. As an example, for the entire period (from 1967-2013), there was only one active PE station in France, located in Langres, 10 km outside the southernmost part of the Meuse basin. The evaporation per catchment was calculated based on interpolation of PE data which was already available from the Scheldt basin (a combination of Uccle and Herentals data).

3.3.2 Interpolated PET

Figure 15 – Evapotranspiration interpolated for all catchments of the Meuse



All interpolated evapotranspiration time series are practically identical because of their geographical proximity. Only the catchments of the upper Meuse and the Sambre differ slightly: with higher values for the Meuse and lower values for the Sambre.

3.4 Balance check of precipitation and discharge

Figure 16 shows the hyetograph and the hydrograph in Chooz. Rainfall is calculated according to the methodology detailed in Section 3.

Figure 16 – Observed hydrograph and hyetograph for the Meuse catchment in Chooz

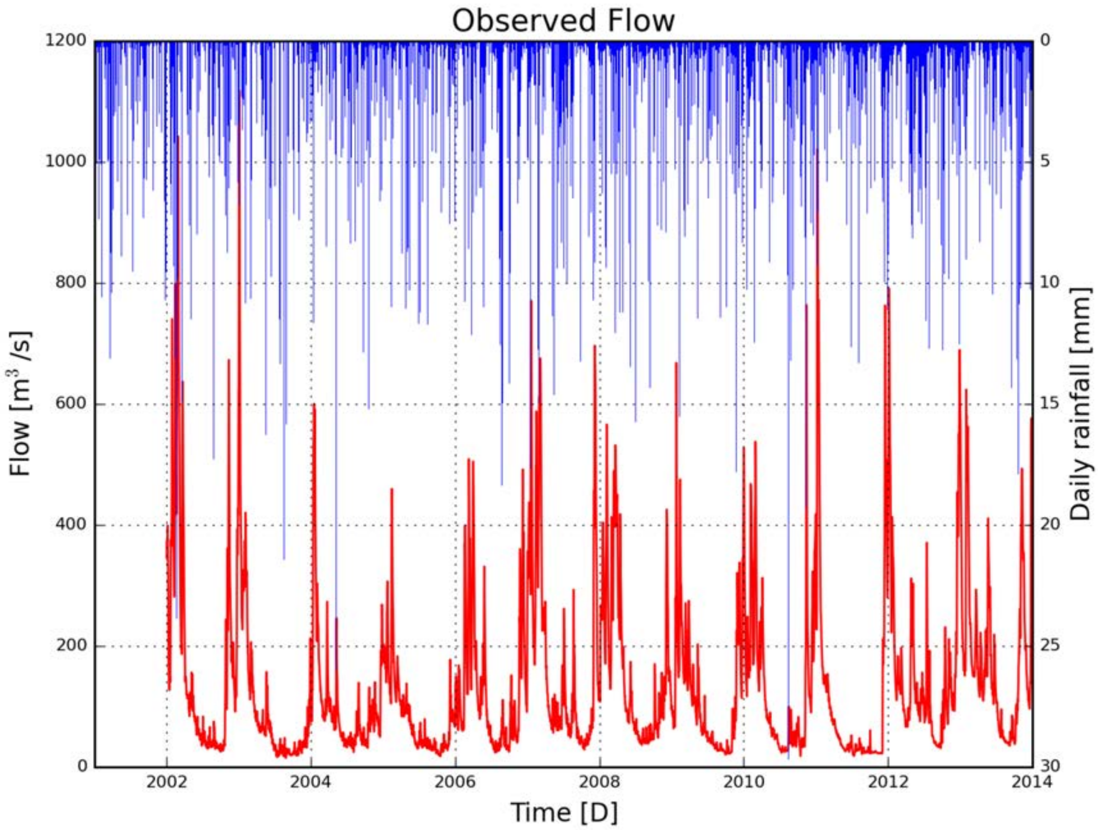
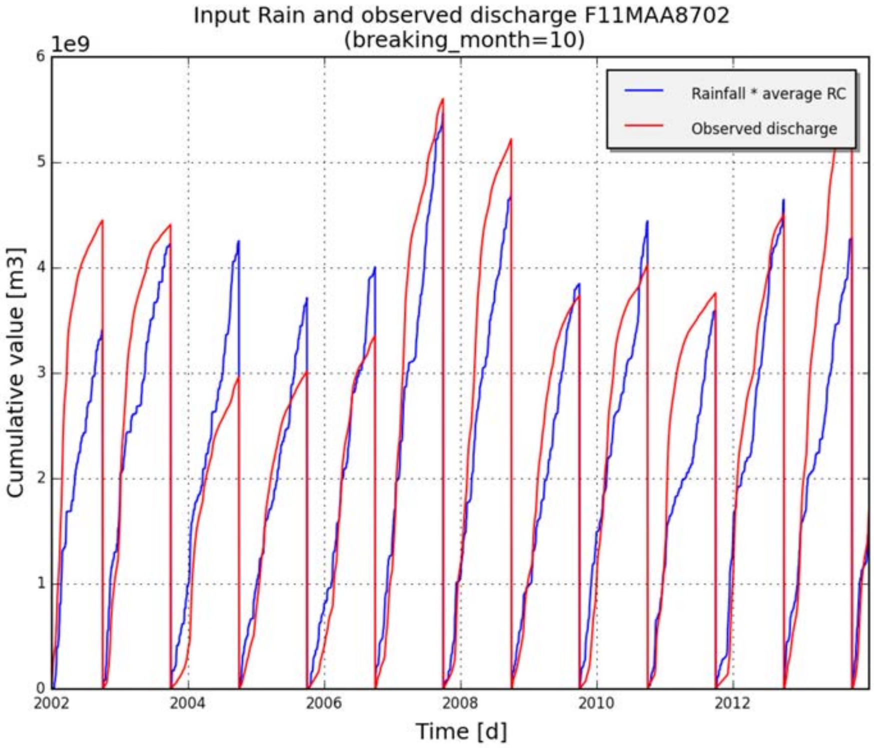


Figure 17 shows cumulative values of observed discharge and rescaled cumulative rainfall according to an average ratio. This ratio is calculated as the total discharge divided by rainfall, based on the whole available time series (Ratio = 0,45 in this instance).

These plots give an idea of the linearity of the relationship between rainfall and discharge. Figure 17 is also an annual balance quality check: interannual differences of rainfall – discharge relationship can be due to interannual variations of evapotranspiration intensity, but it can also be attributed to the catchment complexity and to different hydrological behavior between dry and wet years for example.

Figure 17 – Annual cumulative discharge and scaled rainfall for the Meuse catchment in Chooz (hydrological year from October to September).
This ratio (theoretical average runoff coefficient RC) is calculated based on the whole available time series (ratio = 0,45).



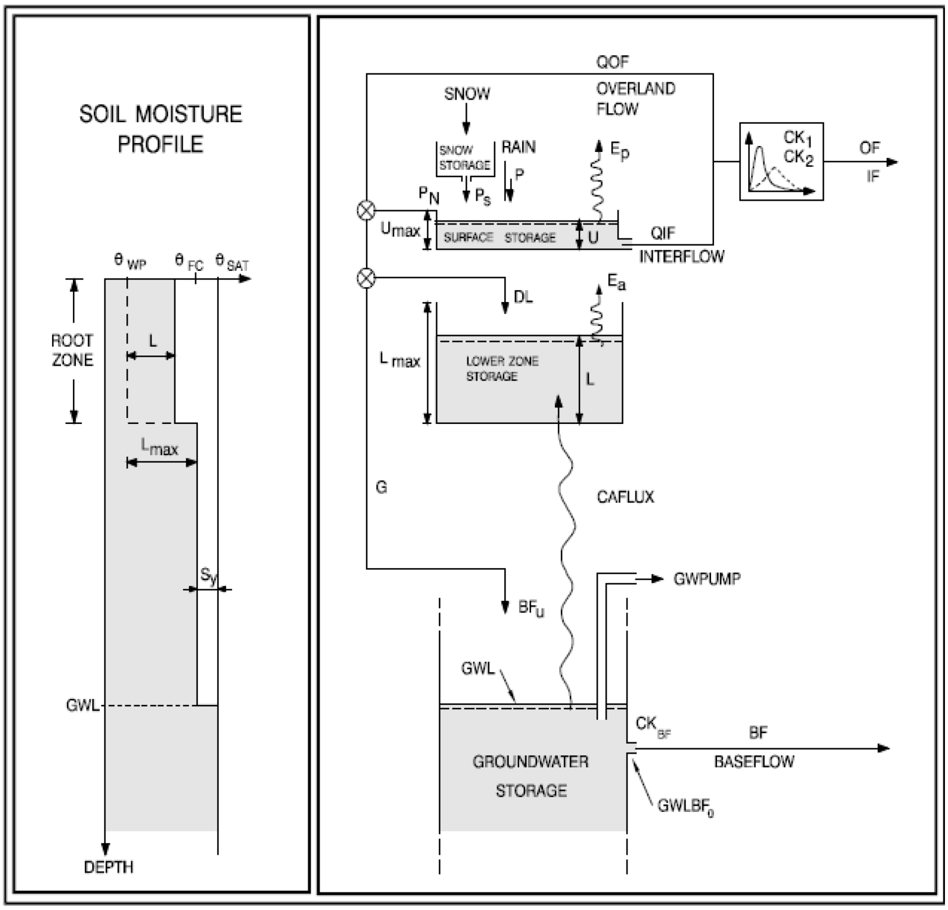
4 Rainfall-runoff modelling methodology

A conceptual rainfall-runoff NAM model was used to simulate long discharge hydrographs for each modelled river of the MIKE BASIN allocation model. NAM is a rainfall-runoff lumped model structure developed by DHI as part as the MIKE 11 software package (DHI, 2009). For each catchment, discharge is simulated based on a unique set of parameters using interpolated rainfall and potential evapotranspiration timeseries as input. A description of NAM is outlined below.

4.1 Structure of the NAM hydrological model

The NAM model is a deterministic, lumped, conceptual rainfall-runoff model, simulating the overland-, inter and base-flow components as a function of the moisture contents in four storages. For this study, the snow module was not considered. NAM included three modelled storages: surface storage, lower storage or root zone, groundwater storage. Figure 18 below shows the general structure of the NAM model. The main components (reservoirs), state and flow variables, and parameters are represented. Being a lumped model, NAM treats each catchment as a single unit. The parameters and variables represent, therefore, average values fo the entire catchment. For that reason, some of the parameters are related to physical processes but final values must be calibrated against hydrological time series. For more detail on the NAM model, please refer to DHI (2009) or Willems (2007).

Figure 18 – Structure of the NAM model (DHI, 2000)



4.2 NAM parameters description

Surface an root zone parameters

1. *Maximum water content in surface storage U_{max}*

Umax [mm] defines the maximum water content in the surface storage (interception, surface depression and uppermost soil). This maximum capacity has to be reached before any excess water occurs. The DHI manual indicate a typical range of 10-20 mm but some extend it to 5-35 (Madsen et al. 2000).

2. *Maximum water content in root zone storage SM_{max} (or L_{max})*

Lmax [mm] defines the maximum water content in the lower or root zone storage. It can be interpreted as the maximum soil moisture content in the root zone available for the vegetative transpiration. Range is about 50-350 or even up to 500.

3. *Overland flow runoff coefficient CQOF*

CQOF [-] determines the extent to which excess rainfall runs off as overland flow and the magnitude of infiltration. It will be related to soil type and infiltration characteristics an also to some extent the recharge condition. Values of the range 0.01-0.90 have been experienced.

4. *Time constant for interflow CKIF*

CKIF [hours] determines, together with Umax, the amount of interflow. It is the dominant routing parameter of the interflow. Range is 500-1000 hours.

5. *Time constant for routing interflow and overland flow CK1 and CK2*

CK1,2 determines the shape of hydrograph peaks. Values depend on the size of the catchment and how fast it responds to rainfall. Typical values are in the range 3-48 hours but sometimes up to 72 (Madsen et al 2000).

6. *Root zone threshold value for overland flow TOF*

No overland flow is generated if the relative moisture content of the lower zone storage , L/Lmax is less than TOF. For catchments with altenating dry and wet periods, the threshold values determine the onset of the flow components in the periods where the root zone is being filled up. Threshold values have no importance in wet periods. The significance of the threshold values vary from catchment to catchment. Values from 0 to 0.7 have been experienced.

7. *Root zone threshod value for interflow TIF*

TIF has the same function for interflow as TOF for overland flow. It is usually unimportant and can in most cases be set to zero.

Groundwater parameters

8. *Baseflow time constant CKBF*

CKBF [hours] determines the shape of the hydrograph in dry periods (exponential decay). It can be estimated from hydrograph recession analysis. CKBF values range from 500 to 5000 hours.

9. *Root zone threshold for groundwater recharge TG*

TG is similar to TOF for recharge. It is an important parameter for simulating the rise fo the groundwater table in the beginning of a wet season.

5 Calibration strategy

5.1 Optimization algorithm

The algorithm used for optimization of NAM parameters is the Non-dominated Sorting Genetic Algorithm II or NSGA II[3]. This algorithm is suitable for optimization problems with multiple objective functions.

Random values are generated in the first iteration. Each generated set of variable values is called an *individual.* A *population* is a group of N solutions in each iteration. In the following iterations the created individuals are going to be "children" of the previous population, that is to say they are going to inherit "features" from couples of individuals chosen in the previous population according to specified selection and crossover techniques. The user can choose to randomly mutate the children features when an offspring is created.

The algorithm will then perform the *evaluation* of the solutions through the Pareto comparison, that is to say a solution dominates, or is better than, another solution if it is better than or equal to the other solution in all objectives and strictly better in at least one objective. A combined population R of parent and children population is formed; the individuals in it are sorted according to non-domination. Since all previous and current population members are included in R, the elitism is ensured. The best N solutions will be the population of the next iteration.

5.2 Objective function

Automatic calibration is consists of optimizing (1) agreement between the average simulated and observed catchment runoff (overall volume error) and (2) overall agreement of the shape of the hydrograph. To assess these two aspects, evaluation has been based on the following goodness-of-fit indexes:

1. Absolute error on cumulated total flow at each time step (to minimize), and
2. Logarithmic Nash-Sutcliff efficiency (to maximize).

These two objectives are suited for NSGA-II optimization because they are contradictory for a number of model parameters. A reduced number of objectives (two) facilitates and fastens the algorithm convergence while ensuring good overall performance of the model. It is also important that these objectives be contradictory in order for the optimum to be well defined. There are generally trade-offs between performance for high and low flows. Therefore, final manual and visual checks will complete performance evaluation with possible focus on low or high flow.

The efficiency E proposed by Nash and Sutcliffe (1970) is defined as one minus the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values during the period under investigation. It is calculated as follows:

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \hat{O})^2} \qquad \text{Eq. 2}$$

with O observed and P predicted values.

To reduce the sensitivity to extreme values, the Nash-Sutcliffe efficiency E is also calculated with logarithmic values of O and P. Through logarithmic transformation of runoff values, the peaks are flattened and the low

[3] Kalyanmoy Deb, Amrit Pratap, Sameer Agarwal, and T. Meyarivan. A Fast Elitist Multi-objective Genetic Algorithm: NSGA-II. IEEE Transactions on Evolutionary Computation, 6(2):182 - 197, April 2002.

flows are kept more or less at the same level. As a result, the influence of low flow values is increased in comparison to the flood peaks, resulting in a higher sensitivity of log NSE to systematic model over- or underprediction (Krause et al. 2005).

The second objective of the algorithm is minimizing the absolute error on cumulated values at each time step (day). This ensures that the water balance remains satisfactory throughout the simulation (all years simulated).

The two goodness-of-fit statistics can be represented in 2 dimensions to represent the set of solutions evaluated by the algorithm. The best pairs constitute the Pareto front.

In order to select one single best solution, the two performance indexes were normalized (or rescaled) across the explored range (Eq. 2): with xmin set to zero for the absolute error, and xmax set to 1 for the logarithmic NSE.

$$x' \frac{x - xmin}{xmax - xmin} \qquad \text{Eq. 3}$$

This normalization resulted in values between 0 and 1 for the absolute error and between -1 and 1 for the NSE. The final solution was then selected among the final Pareto front, looking at the minimum Euclidian distance to theoretical optimum: log NSE = 1 and Absolute Error =0 (Eq. 3).

$$d = \sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \qquad \text{Eq. 4}$$

An example of Pareto front and final selection is shown in Figure 19 and Figure 20.

Figure 19 – All evaluated candidates (individuals) and final population of solutions (Pareto front)

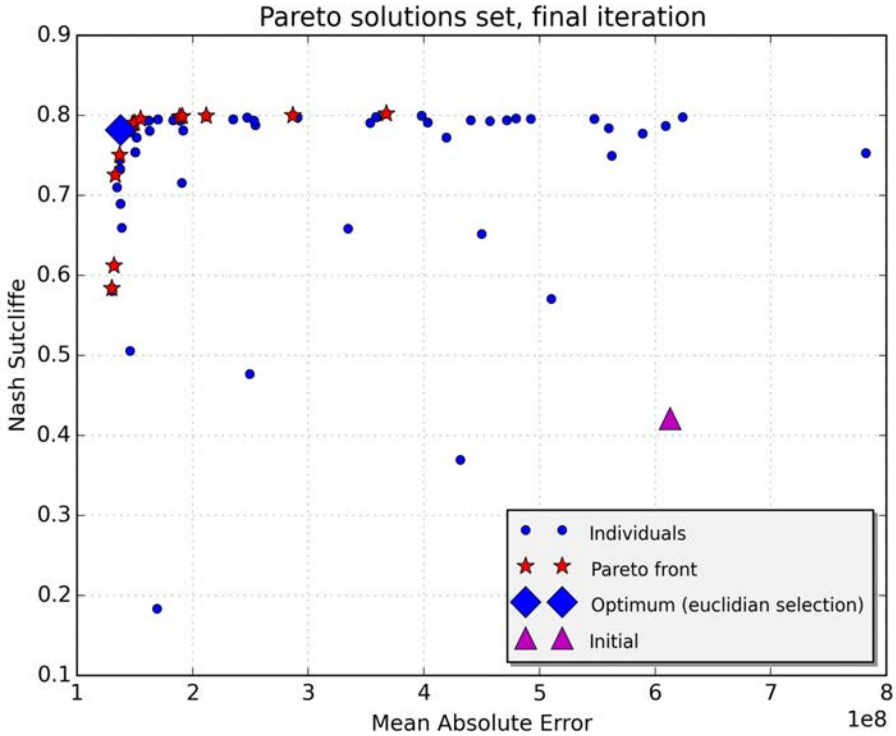
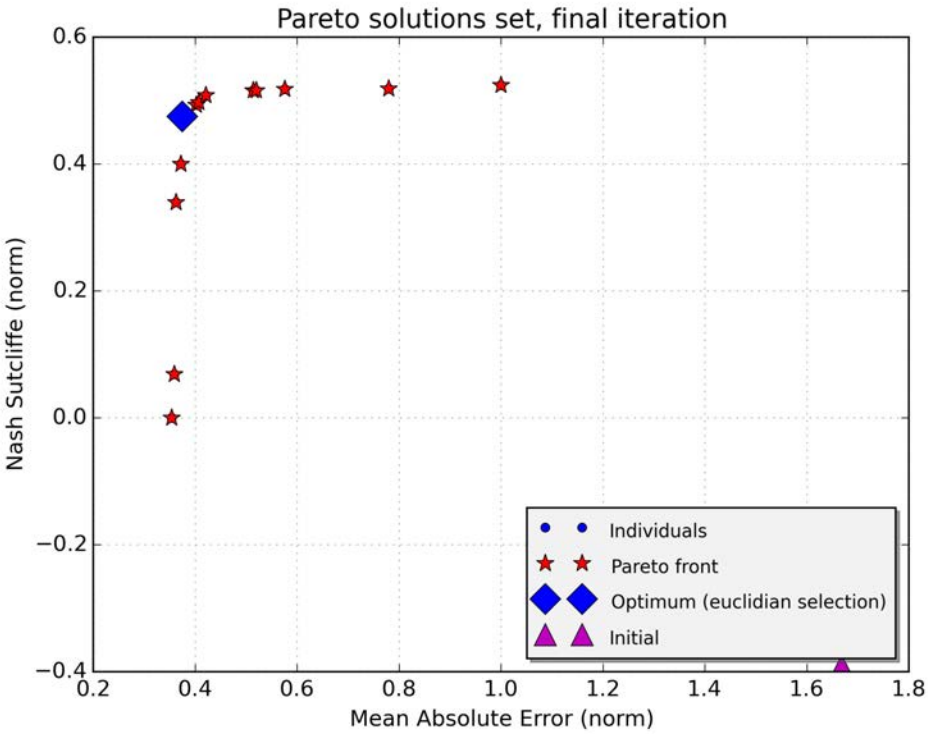


Figure 20 – Rescaled final population of solutions (Pareto front)



5.3 Implementation in Python

The Python version of the NSGA II algorithm was adapted for hydrological optimization purposes using a general framework supporting three rainfall-runoff models: NAM, PDM, VHM and Wetspa. Description of how the NAM model and the other lumped models are being implemented in Python can be found in Vansteenkiste et al. (2011) and Tran et al. (2014 a, b).

The calibration Python shell currently supports the following:

- Optimization of (one or all) model parameters for a given calibration period,
- Evaluation of model parameters for a given validation period,
- Plotting results of various alternative parameter sets on the same plot or separately (for example, the final population generated by the algorithm),
- Generating automatic reports of calibration and validation as Word document,
- Manual calibration for a given calibration period.

As a general rule, all ten parameters (section 4.2) were optimized and explored parameter space was defined by boundaries in Table 5. These boundaries were assumed according to DHI recommandations and past experience with NAM (DHI, 2009; Madsen, 2000). In some particular cases, the optimum was not well defined or the algorithm could not converge in reasonable range and these boundaries were adjusted. Catchment surface area was considered reliable and was not optimized.

Whenever optimization was not delivering good results, boundaries were narrowed down using manual calibration.

Table 5 – NAM parameters and optimization boundaries

Parameters	**Umax**	**SMmax**	**CQOF**	**CKBF**	**CKIF**	**CK1**	**CK2**	**TIF**	**TOF**	**TG**
Lower boundary	8	80	0,1	400	300	3	3	0,1	0,1	0,01
Higer boundary	35	700	0,8	2000	800	72	72	0,9	0,9	0,9

6 NAM model calibration

6.1 Model configuration

In most cases, a calibration time period of 13 years was observed, preferably from January 2001 to December 2013. Nevertheless, different time series were selected when available data were insufficient or unreliable, choosing 13 years of calibration if possible.

Four windows of typical events were selected for visual evaluation:

- 11/2002-04/2003 (high flow) – 6 months
- 06/2008-11/2008 (transition) – 6 months
- 02/2005-11/2005 (low flow) – 10 months
- 11/2010-04/2011 (recession) – 6 months

A warmup period of one year was assumed, with historical rainfall and PET time series when available, or repetition of the first year otherwise.

The calibrated paremeters were validated for the entire time series of available data (also outside of the calibration period). Normally this period ranges from 1967 to 2013

6.2 Model evaluation

While the optimization is limited to two objectives, logarithmic NSE and absolute error, it can be interesting to look at the other indexes listed when evaluating the final results. For example:

- Nash-Sutcliff efficiency
- Relative error (negative or positive) or bias
- Kling-Gupta efficiency (Gupta et al. 2009 and Kling et al. 2012)
- Relative Nash-Sutcliff efficiency

$$E_{rel} = 1 - \frac{\sum_{i=1}^{n}\left(\frac{O_i - P_i}{O_i}\right)^2}{\sum_{i=1}^{n}\left(\frac{O_i - \hat{O}}{O_i}\right)^2} \quad \text{Eq. 5}$$

Since this work focuses on low flows, more importance is given to logarithmic NSE. However, high NSE values should also be sought in order to ensure good enough performance for higher flows as well, as much as possible.

An exact agreement between simulation and observations must not be expected because of different error sources (errors in meteorological input data, errors in measured discharge, errors inherent to the model structure). Calibration can only minimize those errors due to non-optimal parameter values.

NSE and NS_log value above 0.7 can be considered good. Values below zero mean that the predictive power of the model is worse than the measured average. Considering deviation of the measured discharge time series and errors in the meteorological inputs, NSE values are not expected to be above 0.8 (Willems, 2007).

Visual evaluation of the fit between simulated and observed total discharge was also taken into consideration to select the final solution, with a focus on good agreement of simulations for low flows. When useful, Nash-Sutcliffe efficiency (non-logarithmic) was also taken into account for evaluating the final set of candidates (when other fitness indexes were equivalent for example).

6.3 Parameter values of the calibrated models

Table 6 gives the final sets of parameters, after optimization, for the selected catchments of the Meuse basin.

Table 6 – Selected optimized parameter sets for calibrated catchments of the Meuse basin

Catchment	Area	Umax	SMmax	CQOF	CKBF	CKIF	CK1	CK2	TIF	TOF	TG
F11MAA8702	10132	3,8	132	0,322	948	74	23	51	0,69	0,56	0,01
W11MAAPROF	12586	3,8	132	0,322	948	74	23	51	0,69	0,56	0,01
W11SAM7319	2669	4,7	437	0,680	1680	245	26	48	0,90	0,32	0,01
W11OUR5805	3621	6,1	125	0,411	1794	200	12	75,5	0,68	0,36	0,43
W11MEH5820	355,8	12,9	804,5	0,254	2009	655	32	31	0,7	0,30	0,43
W11HOY5990	242,0	5,4	669	0,186	1704	467	61	26	0,9	0,46	0,40
W11JEK553010	465,5	5,0	300	0,100	2000	1000	72	72	0,1	0,30	0,20
W11BER551010	128	2,3	193	0,754	1606	460	46	55	0,9	0,17	0,13

6.4 Goodness-of-fit of the calibrated models

In Table 7, corresponding indexes of log NSE, NSE and absolute error on cumulated discharge are given for each NAM model.

Table 7 – Goodness-of-fit indexes for calibrated catchments of the Meuse : calibration period

Catchment	Name	Station	Log NSE	NSE	Relative error on cumulative discharge
F11MAA8702	Meuse upstream from Chooz	Chooz	0,810	0,802	-2.0 %
W11MAAPROF	Meuse upstream from Profondeville	“Profondeville”	0,840	0,822	-0,6 %
W11SAM7319	Sambre	Salzinne	0,697	0,703	6,2 %
W11OUR5805	Ourthe	Angleur	0,783	0,778	0,3 %
W11MEH5820	Mehaigne	Wanze	0,614	0,627	-2,4 %
W11HOY5990	Hoyoux	Marchin	0,377	0,433	-0.3 %
W11BER551010	Berwijn	Moelingen	0,624	0,620	-0,7 %
W11JEK553010	Jeker	Kanne	-2,959	-4,214	88,2 %

NSE is more than 0,60 for all catchments except for the Hoyoux and the Jeker. The same fitness indexes were also calculated for the whole available discharge time series as validation (Table 8).

Table 8 – Goodness-of-fit indexes for calibrated catchments of the Meuse : validation on the whole time serie available

Catchment	Name	Station	Log NSE	NSE	Relative error on cumulative discharge
F11MAA8702	Meuse upstream from Chooz	Chooz	0.823	0.810	-5,5 %
W11MAAPROF	Meuse upstream from Profondeville	“Profondeville”	0,824	0,802	-8,0 %
W11SAM7319	Sambre	Salzinne	0,694	0,684	3,5 %
W11OUR5805	Ourthe	Angleur	0,811	0,770	2,1 %
W11MEH5820	Mehaigne	Wanze	0,709	0,677	-5,8 %
W11HOY5990	Hoyoux	Marchin	0.377	0.433	-0.5 %
W11BER551010	Berwijn	Moelingen	0,260	0,506	3,7 %
W11JEK553010	Jeker	Kanne	-2,074	-3,424	66,7 %

The model of the Jeker is performing so badly that a constant average value would be better than the hydrological model, to use as input in the allocation model. Detailled results for each subcatchment are given in the automatically generated validation reports (Annex 2).

6.5 Special remarks

6.5.1 Hoyoux

Hoyoux is a small but complex catchment, including karstic formations and former quarries and mining sites as well as current intensive groundwater uptake (source: SPW Geoportail). It is not surprising therefore that the NAM model would be difficult to calibrate. Note that relative NSE (Eq.5) is quite high and equals 0,763.

High peaks are contrasting radically with the normal regime of the Hoyoux (peak at 46 m^3/s in January 2011) and they are poorly modelled by NAM. Therefore, NSE and log NSE values are quite low. However, low flows are much better modelled than peaks. When calculating NSE and logarithmic NSE indexes, over- and underprediction of higher values have a greater influence than the bias on lower values. To counteract this effect, relative NSE is based on relative deviation instead of absolute deviation (see section 6.1). As we are focusing on low flows, the high value of relative NSE for the Hoyoux justifies using this parameter set.

6.5.2 Jeker

The goodness-of-fit remains very unsatisfactory for the Jeker. The Jeker catchment is indeed quite disturbed by mills and small works of art. Measured discharge appears heavily controlled with a very high base flow. Therefore, rainfall-runoff relationship cannot be described by a simple lumped NAM model. As this catchment is a small contributor to the modelled Meuse reach, the average discharge or the interannual average daily discharge can be used as input to the allocation model.

6.5.3 Meuse upstream from Profondeville

For the higher part of the Meuse basin, parameters were calibrated for measurements in Chooz and then transferred to the model for Profondeville, with appropriate interpolated weather data and surface area.

Because the model parameters are calibrated based on discharge data in Chooz, it is interesting to assess the error due to the transfer of parameters to the rest of the catchment upstream from Profondeville, i.e. to the tributary subcatchments. Figure 21 and Figure 22 compare simulated flow in Profondeville and reconstructed flow in Profondeville, from simulation in Chooz and measurements in the other subcatchments. Correspondence is satisfactory for our working scale.

Figure 21 – Simulation in Profondeville using parameters calibrated in Chooz (discontinued black), compared with the sum of simulated discharge in Chooz and observed discharge in the 4 tributary catchments (blue) (from October 2002 to September 2003)

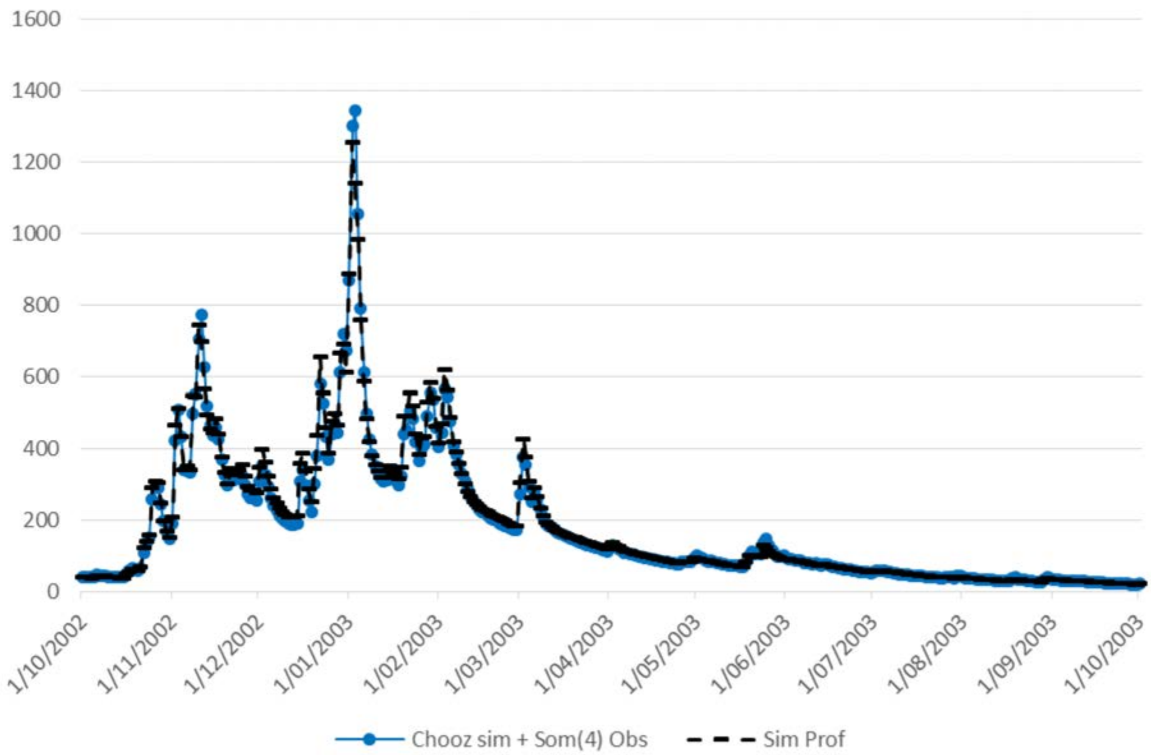
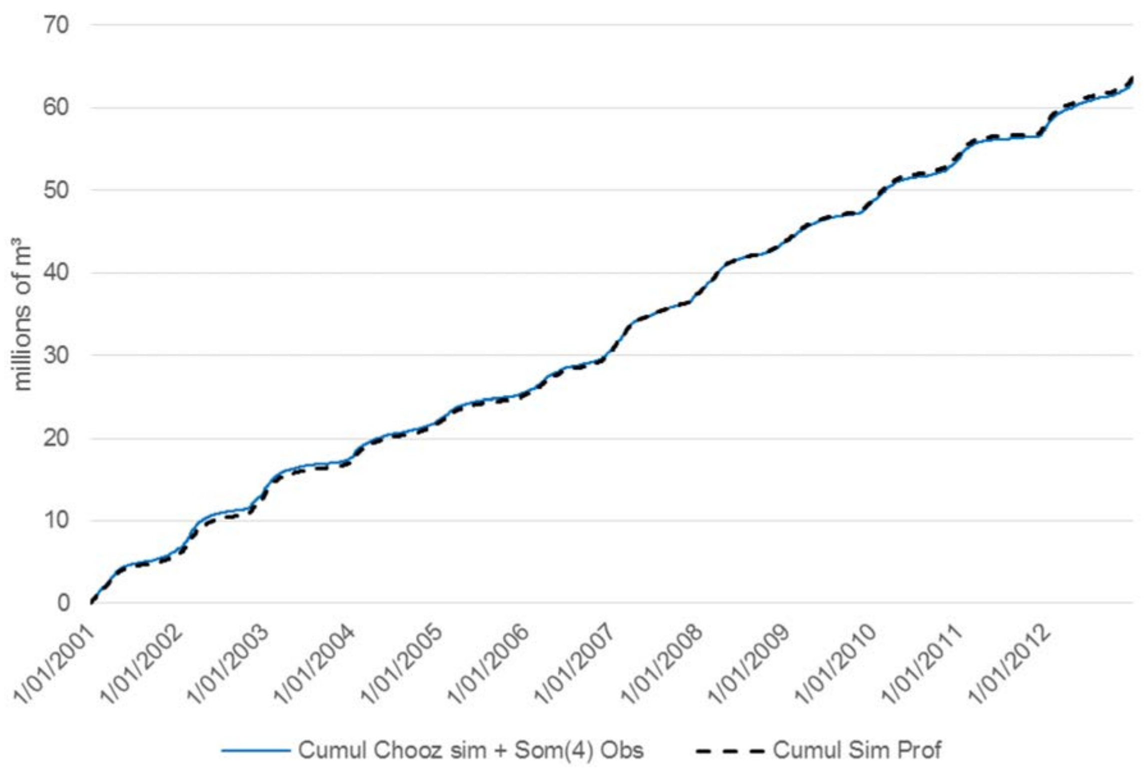


Figure 22 – Cumulative flow simulated in Profondeville using parameters calibrated in Chooz (discontinued black), compared with the sum of simulated discharge in Chooz and observed discharge in the 4 tributary catchments (blue).



6.6 Remaining ungauged zones

The Voer model is given parameters of the Berwijn catchment. Indeed, the relief, soil and land use characteristics of the Voer and Berwijn catchments are similar, as well as their river typology.

The two remaining ungauged zones along the Meuse downstream of Profondeville (Figure 1) are modelled using the parameters of the Mehaigne model because of their geographical proximity and flat, flood-plain nature. In addition, the industrial Meuse valley and the Mehaigne catchment are both quite urbanized. In this instance, the Mehaigne is preferred to the Hoyoux (also close geographically) because of the uncharacteristic behavior of the latter (see 6.5.1).

Parameters of the ungauged catchments are synthetized in Table 9.

Table 9 – Transferred parameters

Catchment	**Area**	**Umax**	**SMmax**	**CQOF**	**CKBF**	**CKIF**	**CK1**	**CK2**	**TIF**	**TOF**	**TG**
V11VOE000010	62,9	2,3	193	0,754	1606	460	46	55	0,9	0,17	0,13
W11MAA0030	503,2	12,9	804,5	0,254	2009	655	32	31	0,7	0,30	0,43
W11MAA0040	370,1	12,9	804,5	0,254	2009	655	32	31	0,7	0,30	0,43

6.7 Control: Meuse in Amay

A simulated time series for Amay can be constructed, aggregating together all simulation results from the 5 catchments upstream Amay ('W11MAAPROF', 'W11SAM7319', 'W11MEH7242', 'W11HOY5990') and ungauged zone upstream Amay ('W11MAA0030'). This section present this simulated time series and goodness of fit in Amay. Calibration periods varied for each subcatchment depending on available data (see Table 2). For Amay, discharge data is available from Jan 1996 until May 2013. Calculated fitness indexes for this validation period were:

Table 10 – Goodness-of-fit indexes for the Meuse in Amay (control)

	All year	**Summer**	**Winter**
Logarithmic Nash-Sutcliff efficiency	0.850	0.608	0.726
Nash-Sutcliff efficiency	NS : 0.822	NS : 0.659	0.713
Relative Nash-Sutcliff efficiency	0.859	0.782	0.627
Kling-Gupta efficiency	0.830	0.738	0.701
Relative error on cumulative discharge	-0.04 %	3.12 %	-0.55 %

All NSE values are higher than 0.8 which show a good general fitness. Logarithmic NSE was used as objective function for the optimization and is consequently even higher than NSE. This gives indication that low flows are being modelled adequately.

For visual assessment, Figure 23 shows simulated and observed discharge in Amay for the whole validation period. Figure 24 and Figure 25 give some closer view on specific events of high and low flow, as well as transition and snow-sensitive periods. Some peaks are simulated slightly before they are recorded by the gauge (Figure 24) but this might be due to the absence of the snow module and the relatively coarse time step (daily). High peaks are often underestimated but as the water balance is respected, this should not have much impact on the results of the water availability model. The model performance is the poorest during the years 2011 and 2013, when total flow is underestimated during recession events.

Figure 23 – Simulated and observed total flow in Amay for validation period

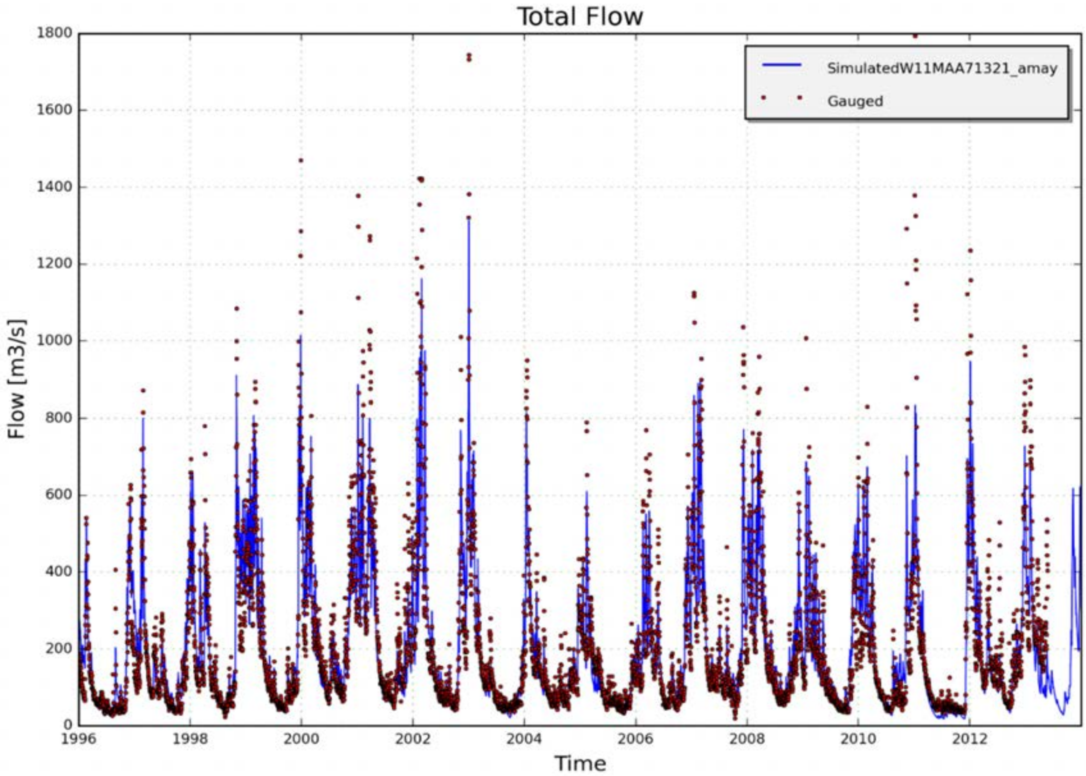


Figure 24 – Simulated and observed total flow in Amay (detail)

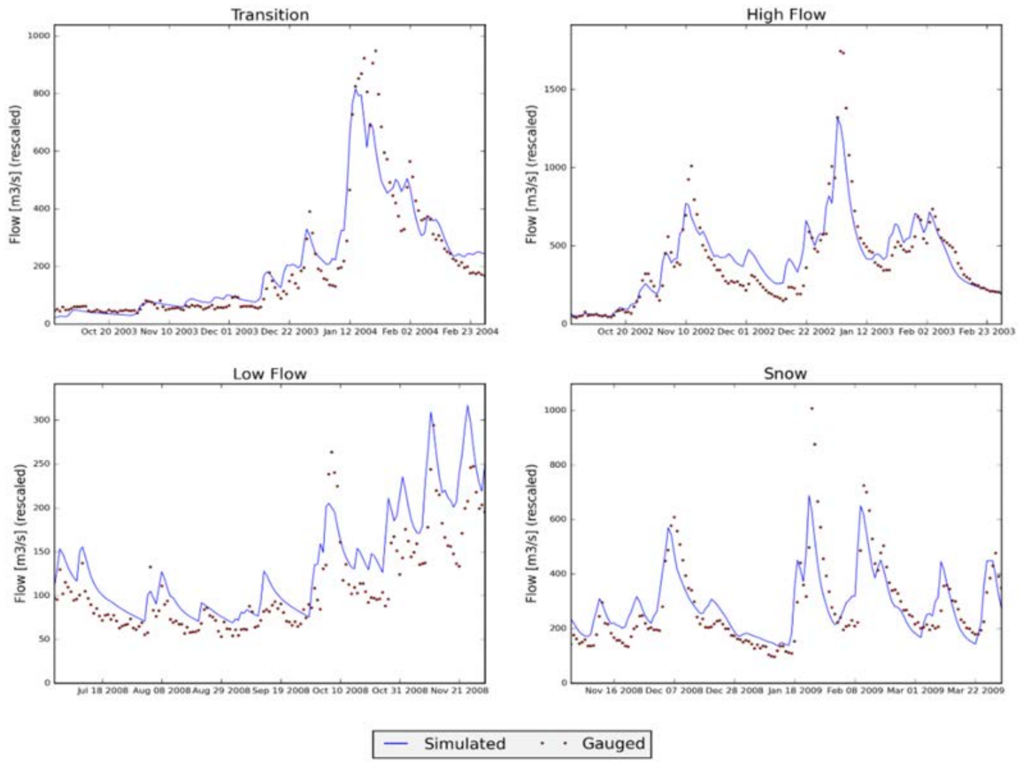


Figure 25 – Simulated and observed total flow in Amay (detail 2)

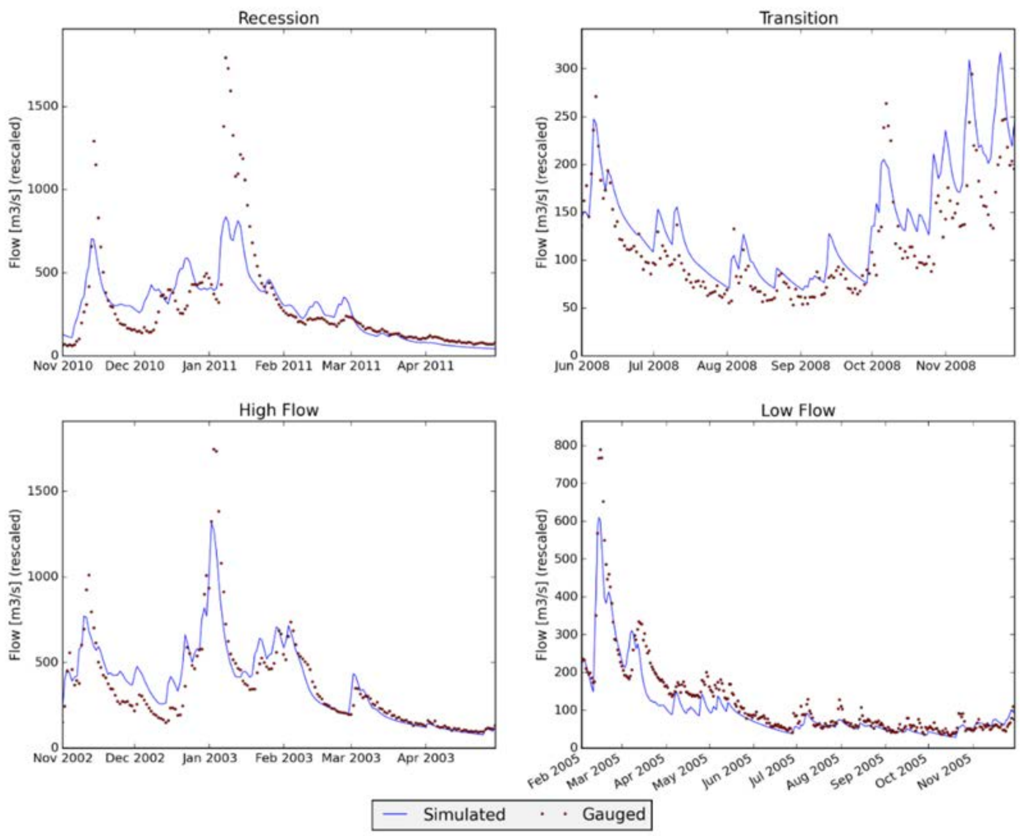


Figure 26 and Figure 27 show simulated and observed *cumulative* discharge time series. Relative error calculated based on cumulated discharge values at each time step is equal to:

There is a slight difference of balance during hydrological year 1999 (overestimation by the model) and then 2001 and 2002 (underestimation by the model). These annual discrepancies balance each other out by the end of the validation period (17 years).

Figure 26 – Simulated and observed cumulated flow in Amay for validation period

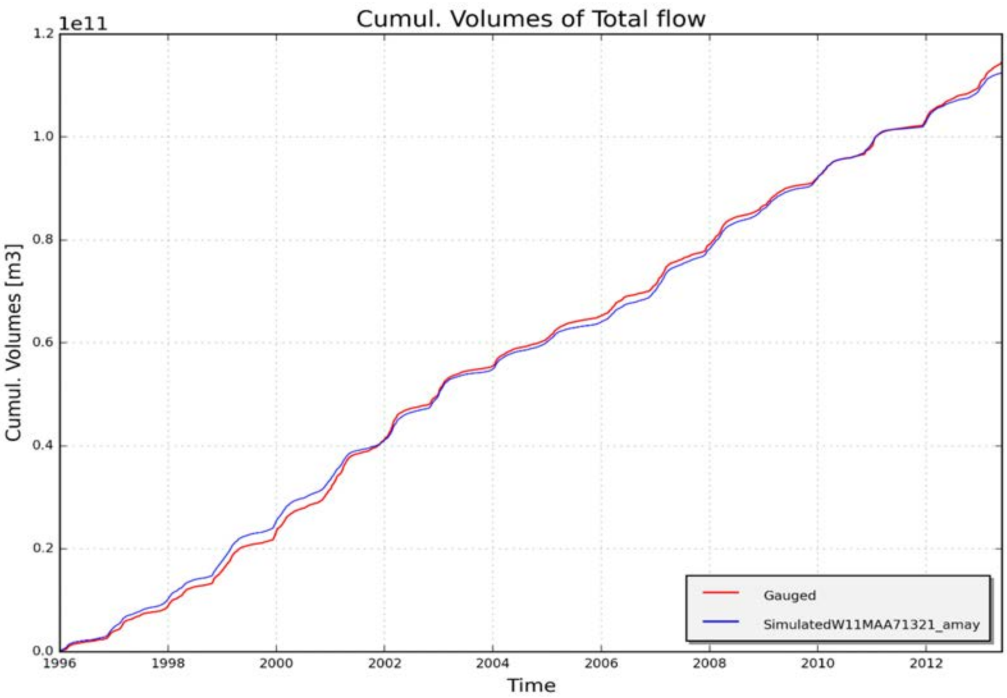
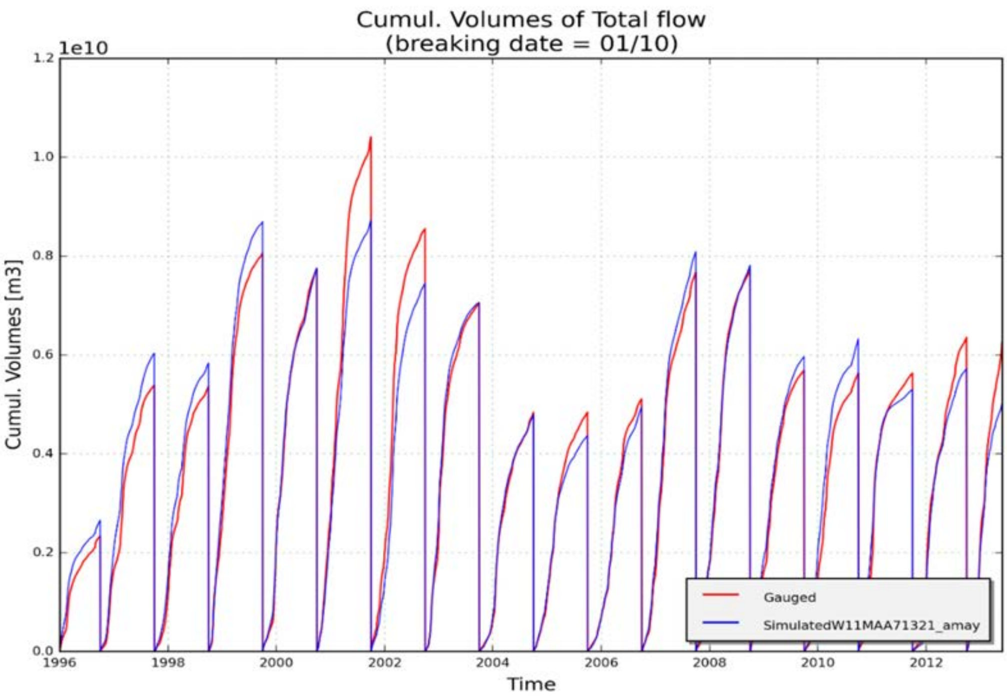


Figure 27 – Simulated and observed total *annual* cumulated flow in Amay with optimum parameters for validation period



7 Conclusions and recommendations

NAM models were set up for 11 subcatchments of the Meuse in order to produce long time series of discharge for a MIKE Basin water availability model. Automatic calibration was performed by optimization, using a genetic algorithm, on 8 gauged subcatchments. The five calibrated subcatchments upstream Visé were: the Sambre, the Haute Meuse, the Ourthe, the Hoyoux and the Mehaigne. Three additional small catchments downstream Visé were needed for the simulation of the situation on the Albert canal and the Campine canal. The Berwijn (Berwinne) and the Jeker (Geer) were calibrated based on available timeseries. The model for the Voer used the same parameter values as the Berwijn.

Calibration periods varied from 8 to 13 years between 2001 and 2014. Parameters calibrated for the Mehaigne were transferred to simulate runoff for the two remaining ungauged zones (along the Meuse downstream Profondeville and Amay). The models upstream Amay were validated using measured discharge timeseries in Amay (1996-2013).

Given the regional scale of the models presented in this report, calibration was deemed satisfactory for the purpose of water availability modelling. Limitations of the approach were identified for modified catchments such as the Jeker and the Samber. Therefore it should be kept in mind, in further study and extrapolations, that rainfall-runoff NAM models were calibrated based on potentially disturbed discharge time series for these two catchments.

Moreover, because of the lumped character and the fixed structure of the NAM model, some hydrological processes and interactions have been ignored (groundwater interactions for the Bocq and the Hoyoux for instance, see Gailliez 2013). In future, comparison with other conceptual model structures and with distributed models will complete this first NAM calibration exercise. Comparison with other model structures should also give a better view on the uncertainties associated with the model structure on the one hand, and the calibration process on the other hand.

8 References

Gailliez S., 2013. *Estimation des débits d'étiage pour des sites non jaugés. Application en Région wallonne (Thèse de doctorat).* Université de Liège – Gembloux Agro-Bio Tech, 190 p, 118 fig., 39 tabl

Gupta, Hoshin V., Harald Kling, Koray K. Yilmaz, Guillermo F. Martinez. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. Journal of Hydrology, Volume 377, Issues 1-2, 20 October 2009, Pages 80-91. DOI: 10.1016/j.jhydrol.2009.08.003. ISSN 0022-1694

Danish Hydraulic Institute (DHI), 2009. MIKE 11, A Modelling System for Rivers and Channels, Reference Manual. DHI Water & Environment, Horsholm, Denmark.

IMDC, 2008. *Bilan hydrique en l'état actuel, Etude des ressources en eau dans le cadre de la liaison Seine – Escaut Est*, MET – D213. Direction des Recherches Hydrauliques, Cahier spécial des charges n° MS/213/07/02, Rapport Final 27 septembre 2008 : I/RA/11321/08.052/PIB

IMDC, (Franken, T.; Smets, S.; Pereira, F.; Mostaert, F.), 2010. *Bijstand modelinstrumentarium hydrologie: Opmaak toolbox hydrologische modellering: Gebruikershandleiding*. Versie 2_0. WL Rapporten, 706_15b. Waterbouwkundig Laboratorium en IMDC: Antwerpen, België

Kling, H., M. Fuchs, and M. Paulin, 2012. Runoff conditions in the upper Danube basin under an ensemble of climate change scenarios. Journal of Hydrology, Volumes 424-425, 6 March 2012, Pages 264-277, DOI:10.1016/j.jhydrol.2012.01.011

Krause P., Boyle D.P., Bäse F., Comparison of different efficiency criteria for hydrological model assessment, *Advances in Geosciences*, 5, 89–97, 2005

Madsen H., Automatic calibration of a conceptual rainfall–runoff model using multiple objectives, DHI Water & Environment, Agern Alle ́ 11, DK-2970 Hørsholm, Denmark 2000

Nash, J. E. and Sutcliffe, J. V., 1970. River flow forecasting through conceptual models, Part I - A discussion of principles, *J. Hydrol.,* 10, 282–290.

Tran, Q. Willems, P.; Pereira, F.; Nossent J; Mostaert, F. (2021). Effect of climate change on the hydrological regime of navigable water courses in Belgium: Sub report 7 – Development of a framework for flexible hydrological modelling. Version 1.1. FHR Reports, 00_130_7. Flanders Hydraulics Research: Antwerp, Belgium.

Tran, Q. Willems, P.; Pereira, F.; Nossent J; Mostaert, F. (2021). Effect of climate change on the hydrological regime of navigable water courses in Belgium: Sub report 8 – Implementation and testing of a framework for flexible hydrological modelling. Version 1.1. FHR Reports, 00_130_8. Flanders Hydraulics Research: Antwerp, Belgium.

Vansteenkiste, T., Pereira, F., Willems, P., Mostaert, F., 2011. *Effect of climate change on the hydrological regime of navigable water courses in Belgium: Subreport 2 – Climate change impact analysis by conceptual models.* WL Rapporten, project 706_18, Waterbouwkundig Laboratorium & KU Leuven, December 2011, 57 p.

Willems, P., 2007. Modelling guidelines for Water Engineering. 4. Model calibration and validation.

Appendix 1 Rainfall interpolation results

Table 11 – Annual rainfall and interannual average in the main catchments of the Meuse basin (mm)

Year	Ourthe	Mehaigne	Hoyoux	Jeker	Samber	Maas upstr. Profonde ville	Voer	ungauged Meuse Amay-Monsin & Berwijn	ungauged Meuse Prof-Amay
1965	1300	1096	1155	1006	1127	1209	1125	1122	1113
1966	1360	1129	1182	1047	1099	1194	1179	1173	1105
1967	956	757	875	674	803	955	724	778	779
1968	968	723	750	677	835	887	745	703	739
1969	967	788	830	700	790	859	826	699	779
1970	1104	745	927	707	843	1007	821	790	765
1971	758	572	641	577	673	709	621	578	583
1972	845	698	760	662	780	830	733	665	718
1973	945	694	793	656	675	784	713	684	695
1974	1221	963	1067	939	1039	1033	989	861	979
1975	765	668	725	571	744	769	627	644	676
1976	717	515	593	475	528	655	597	506	508
1977	1064	882	887	782	866	1027	939	784	895
1978	923	728	783	672	772	954	836	707	780
1979	1099	830	927	723	926	1117	819	841	888
1980	1140	867	983	774	945	1050	893	845	922
1981	1303	1019	1134	959	1050	1227	1067	1061	1039
1982	1108	859	947	841	912	1052	851	891	856
1983	1073	801	841	733	853	1019	798	834	826
1984	1182	920	1036	911	938	1068	1016	977	905
1985	872	763	816	679	758	824	767	735	725
1986	1123	897	975	830	960	1102	842	876	862
1987	1185	863	995	890	991	1076	949	924	881
1988	1269	987	1057	949	1069	1191	985	1010	990
1989	975	726	879	708	797	906	702	801	751
1990	986	676	860	668	776	969	717	728	704
1991	900	697	806	659	752	808	649	690	715
1992	1078	888	973	824	1031	995	852	947	863
1993	1084	810	948	783	962	1073	821	818	859
1994	1088	783	839	737	871	1047	804	759	772
1995	1166	802	999	752	954	1122	781	873	882
1996	786	652	665	626	743	793	651	633	670
1997	961	708	770	689	801	912	744	798	696
1998	1237	951	928	960	999	1028	1016	968	921

1999	1195	919	1088	871	986	1092	937	961	932
2000	1159	892	1022	904	1024	1039	882	954	915
2001	1291	955	1116	991	1104	975	983	960	1012
2002	1278	1053	1150	893	1111	1130	1009	979	1064
2003	840	685	814	626	684	772	653	696	732
2004	1039	833	940	836	809	930	856	828	852
2005	945	657	741	663	729	786	747	694	686
2006	1052	783	1139	753	861	1006	814	907	870
2007	1220	886	1053	868	936	1143	999	919	940
2008	1159	881	1040	858	957	1029	920	1062	890
2009	1008	705	759	700	795	954	787	754	714
2010	889	735	799	753	854	910	811	850	715
2011	917	653	779	677	751	831	698	632	673
2012	1131	891	948	872	895	1064	860	881	899
2013	955	750	841	675	833	950	759	730	753
Total	**51586**	**39734**	**44576**	**37778**	**42988**	**47862**	**40919**	**40509**	**40486**
Average	**1053**	**811**	**910**	**771**	**877**	**977**	**835**	**827**	**826**

Appendix 2 Result reports on NAM calibration for each subcatchment

Calibration and validation of NAM parameters for catchment "W11HOY5990" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11HOY5990 (Meuse)

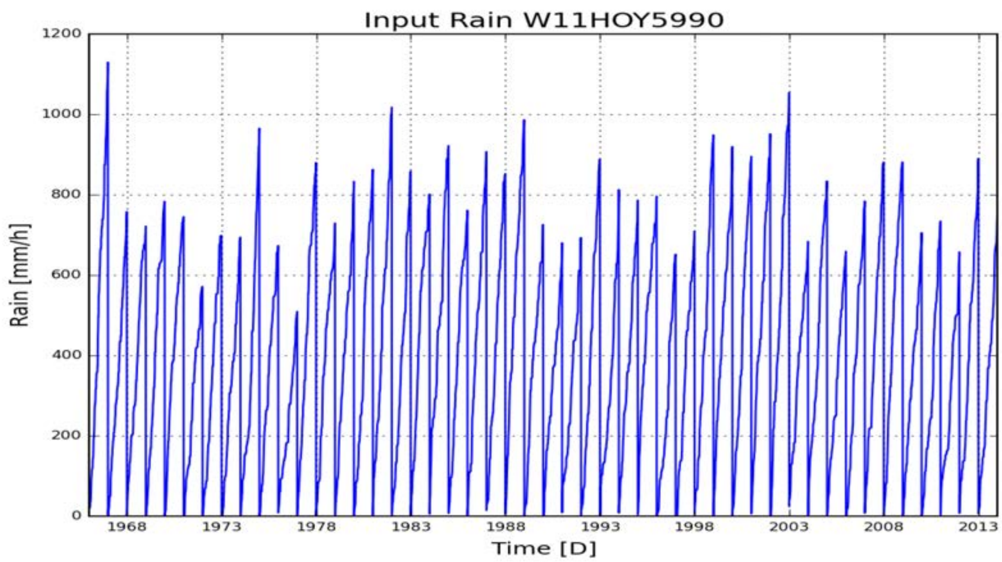
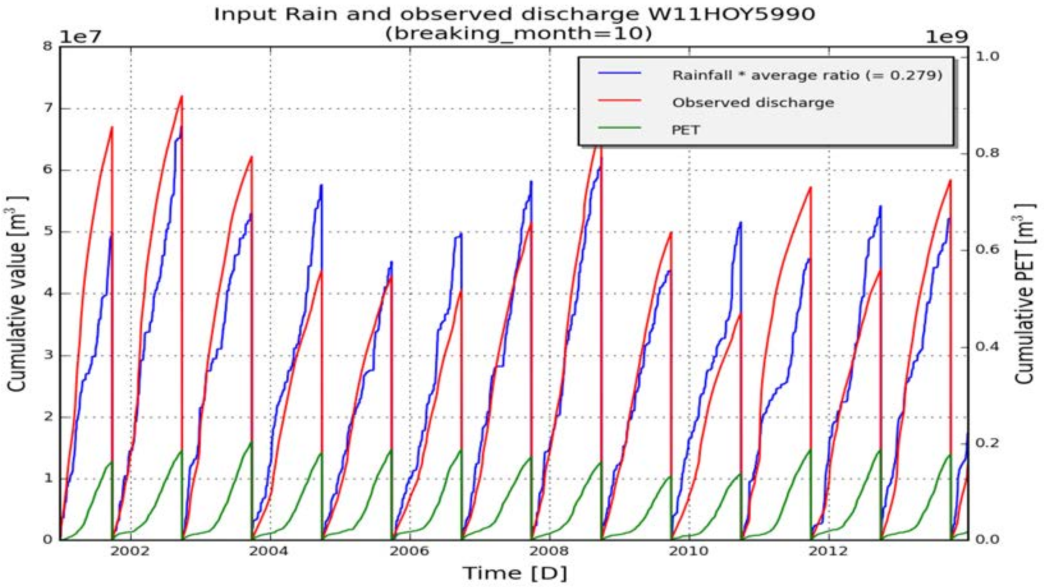


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11HOY5990 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11HOY5990
subcatchment_area [m²]	242000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 5.4), ('SMmax.C', 669.0), ('CQOF.C', 0.19), ('CKBF.C', 1704.0), ('CKIF.C', 467.0), ('CK1.C', 61.0), ('CK2.C', 26.0), ('TIF.C', 0.9), ('TOF.C', 0.46), ('NAM.TG.C', 0.4)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	Summer	Winter
RelErr	-0.3 %	-4.0 %	1.2 %
NS	0.433	-0.152	0.324
NS_log	0.377	-0.561	0.608
NS_rel	0.763	0.317	0.834
KGE	0.569	0.463	0.332

Goodness of fit for validation period (all available period 2001 - 2013)

	Full year	Summer	Winter
RelErr	-0.5 %	-4.1 %	1.0 %
NS	0.433	-0.151	0.324
NS_log	0.377	-0.562	0.608
NS_rel	0.763	0.317	0.834
KGE	0.567	0.463	0.331

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HOY5990,
station Hoyoux, Marchin (complete simulation period 1967-2013)

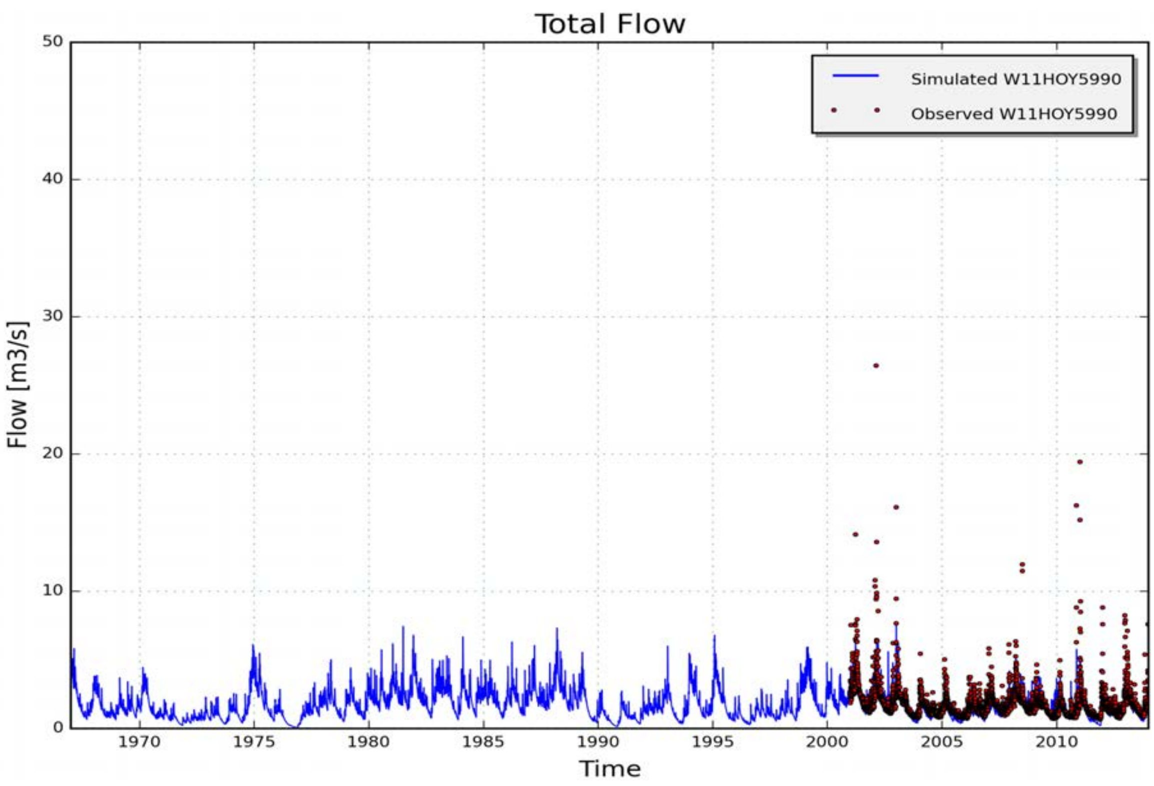


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HOY5990, station Hoyoux, Marchin(calibration period)

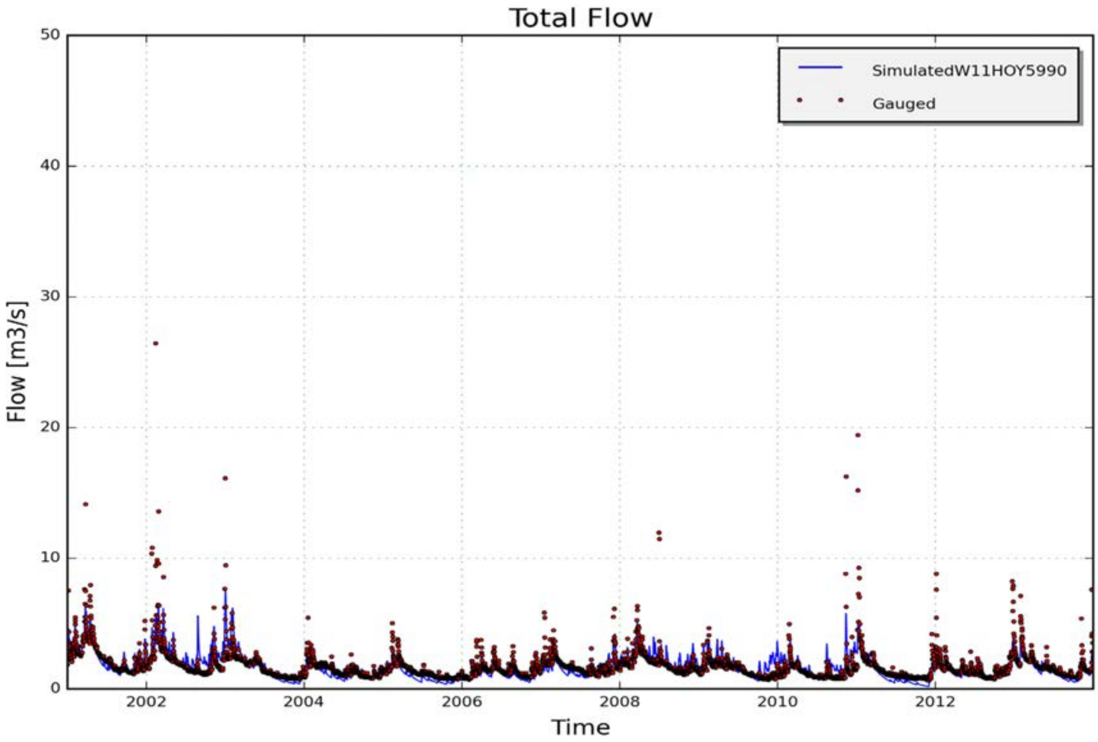


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11HOY5990, station Hoyoux, Marchin (calibration period)

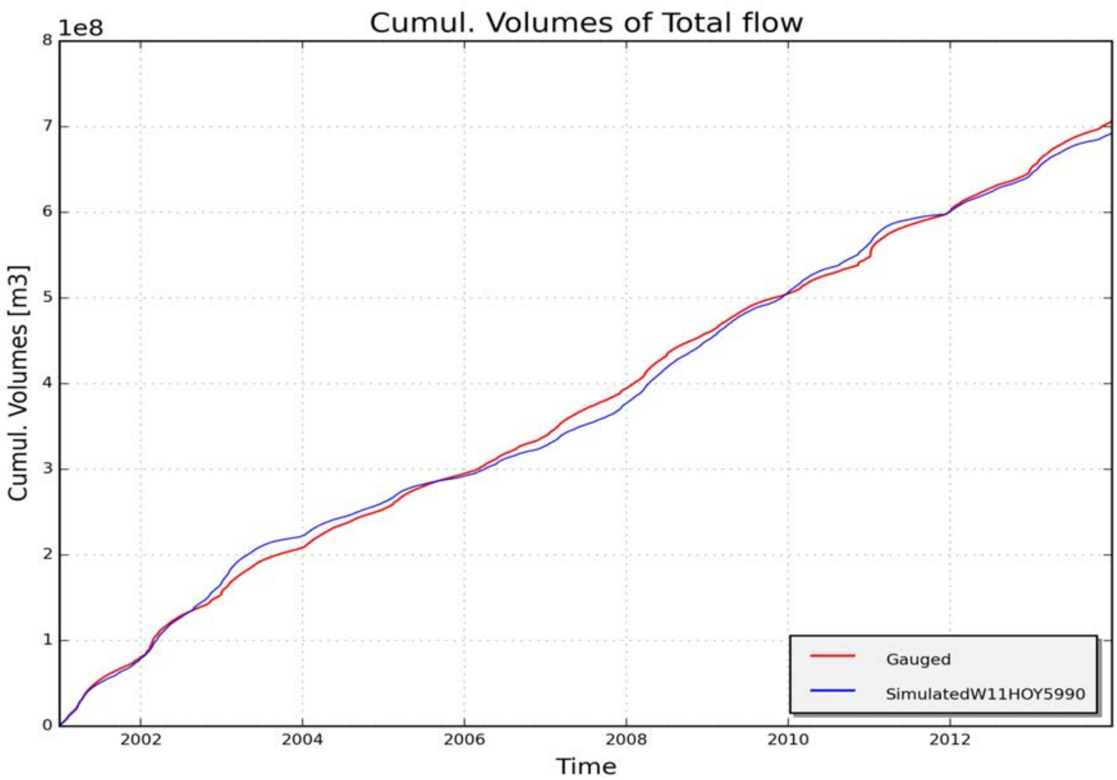
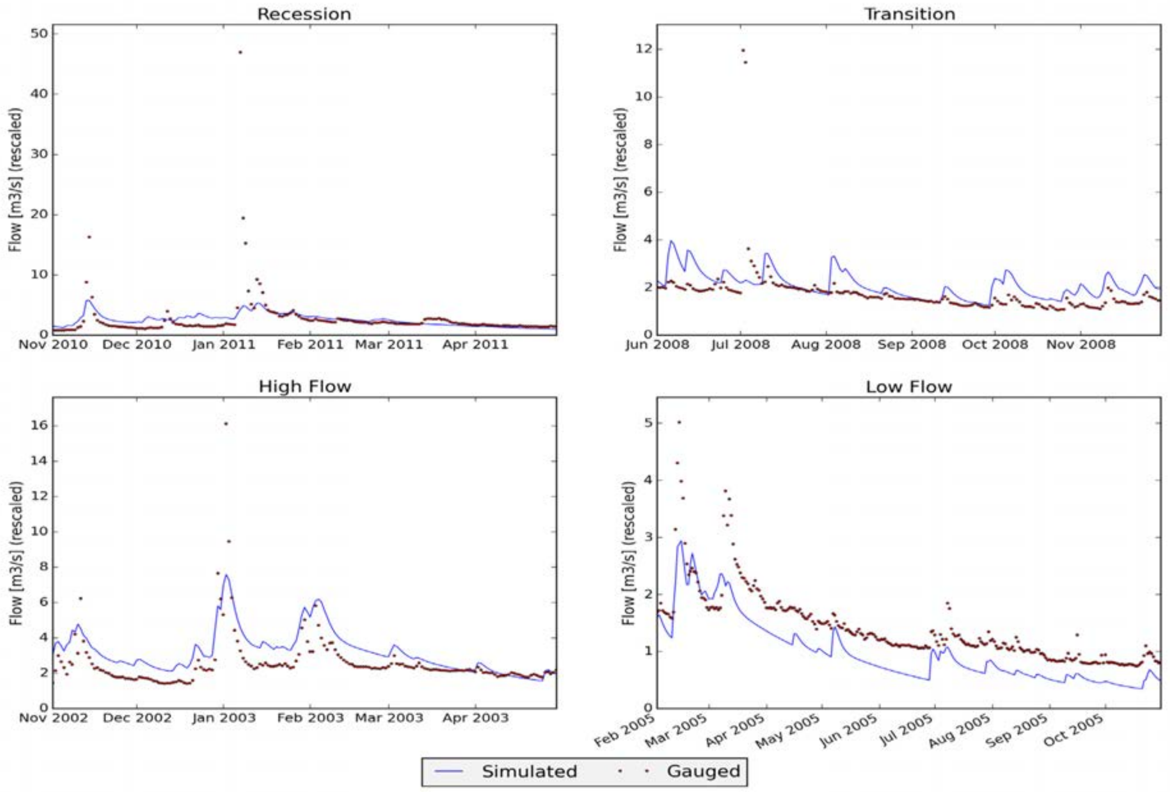


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11HOY5990, station Hoyoux, Marchin



Calibration and validation of NAM parameters for catchment "W11MEH5820" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11MEH5820 (Meuse)

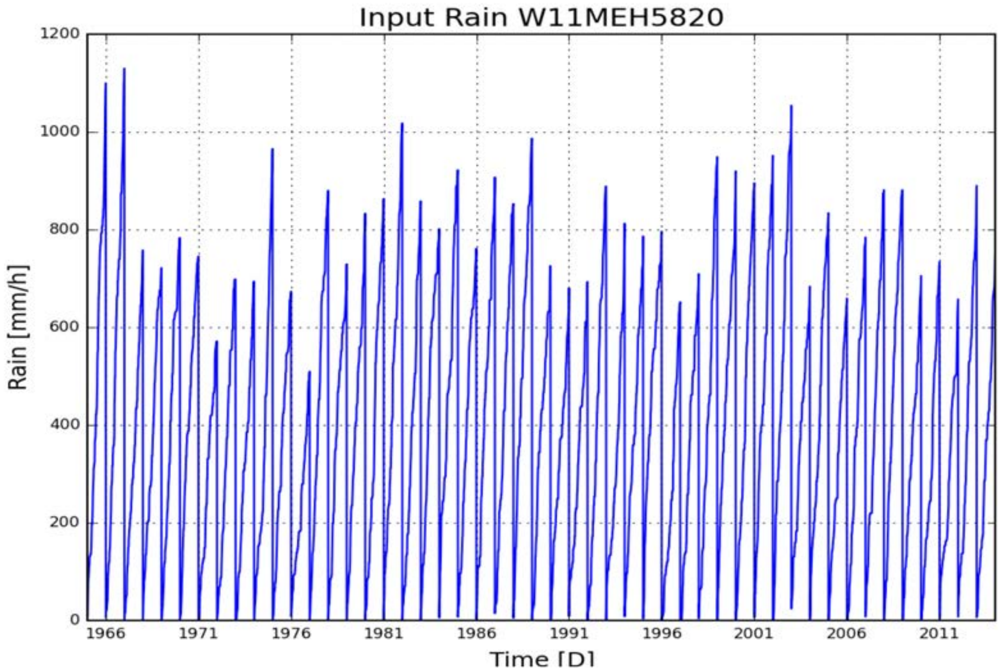
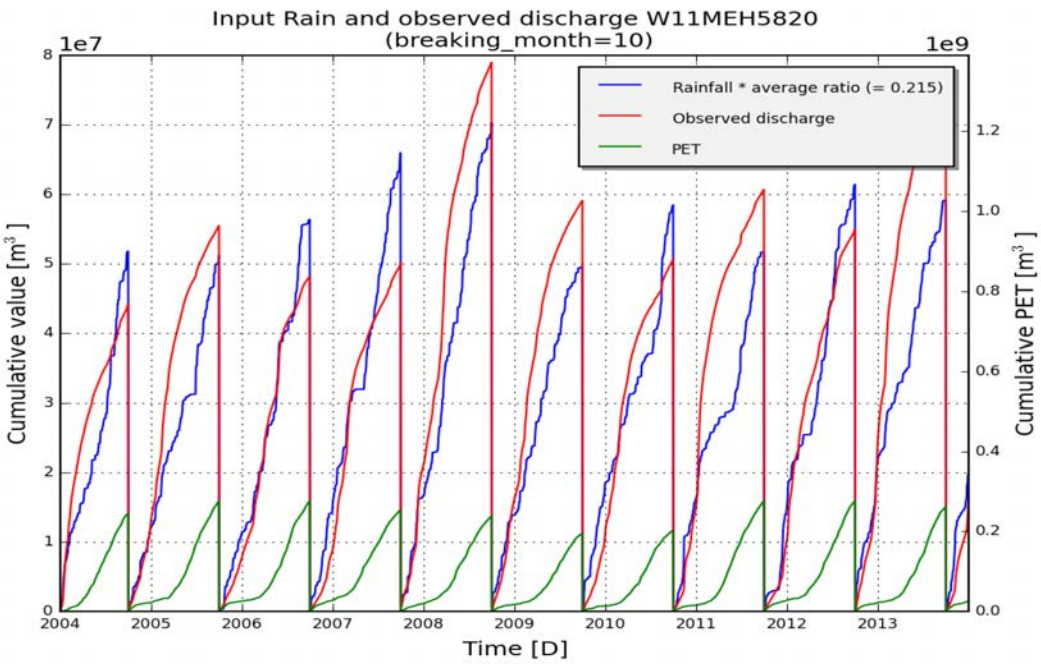


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11MEH5820 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11MEH5820
subcatchment_area [m^2]	355800000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 12.9), ('SMmax.C', 804.5), ('CQOF.C', 0.25), ('CKBF.C', 2009.0), ('CKIF.C', 655.0), ('CK1.C', 32.0), ('CK2.C', 31.0), ('TIF.C', 0.7), ('TOF.C', 0.3), ('NAM.TG.C', 0.43)]

Goodness of fit for calibration period (2004 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-2.4 %	23.5 %	-14.6 %
NS	0.627	-0.231	0.526
NS_log	0.614	-0.004	0.523
NS_rel	0.699	0.142	0.717
KGE	0.703	0.443	0.524

Goodness of fit for validation period (all available period 2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-5.8 %	13.6 %	-15.9 %
NS	0.677	0.39	0.593
NS_log	0.709	0.41	0.644
NS_rel	0.797	0.781	0.806
KGE	0.663	0.545	0.526

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MEH5820, station Mehaigne, Wanze (complete simulation period 1967-2013)

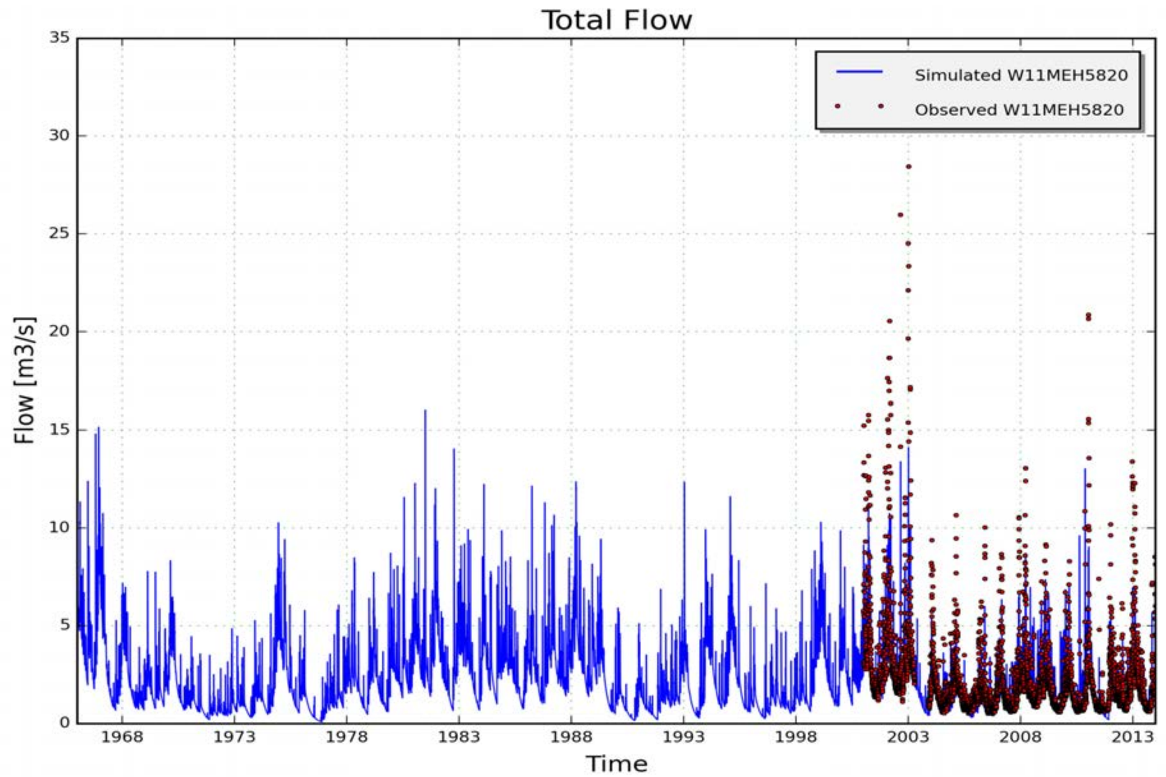


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MEH5820, station Mehaigne, Wanze(calibration period)

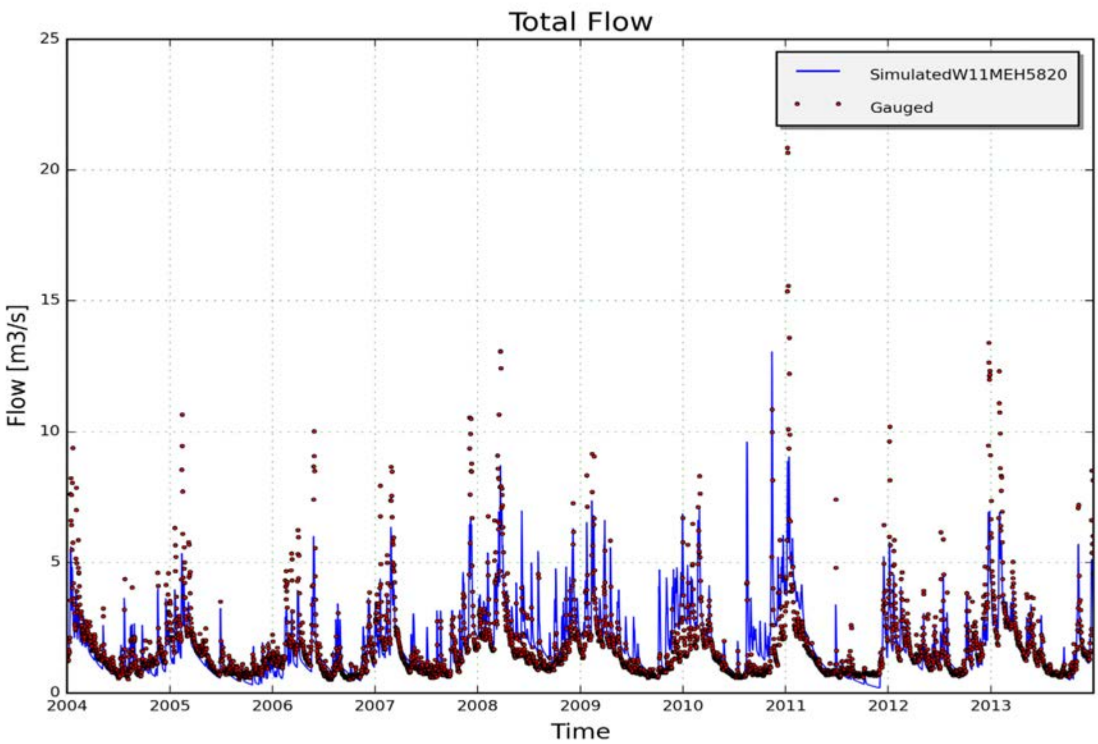


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11MEH5820, station Mehaigne, Wanze (calibration period)

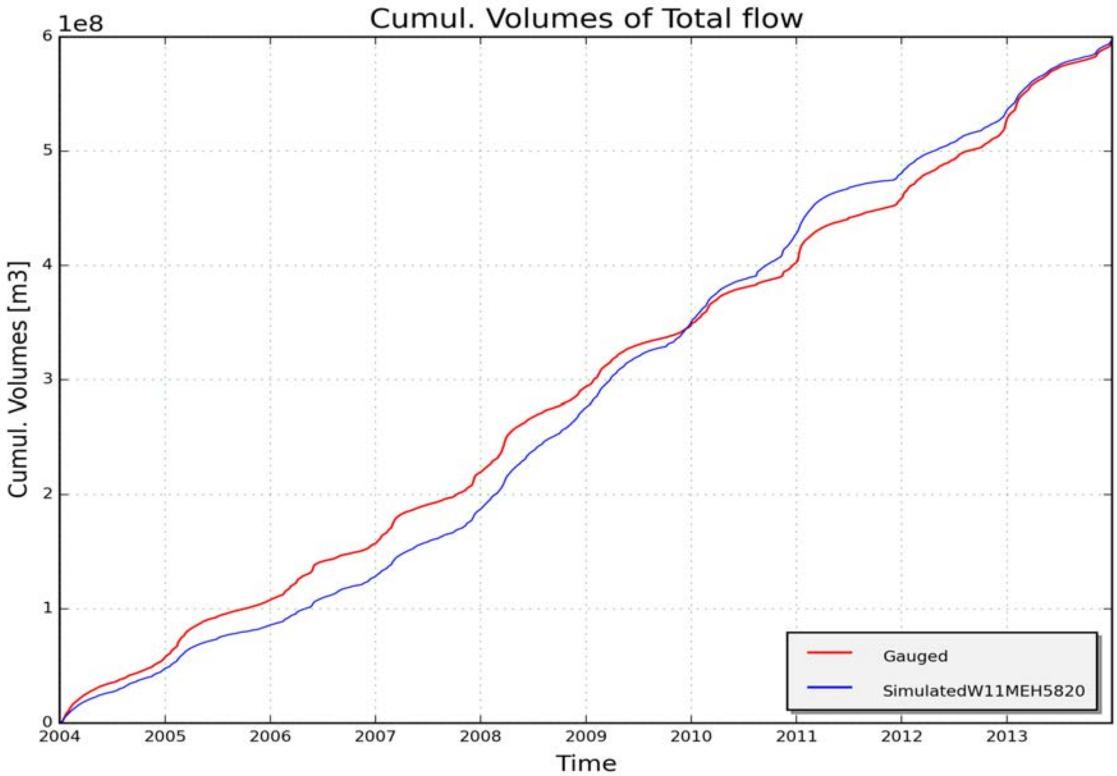
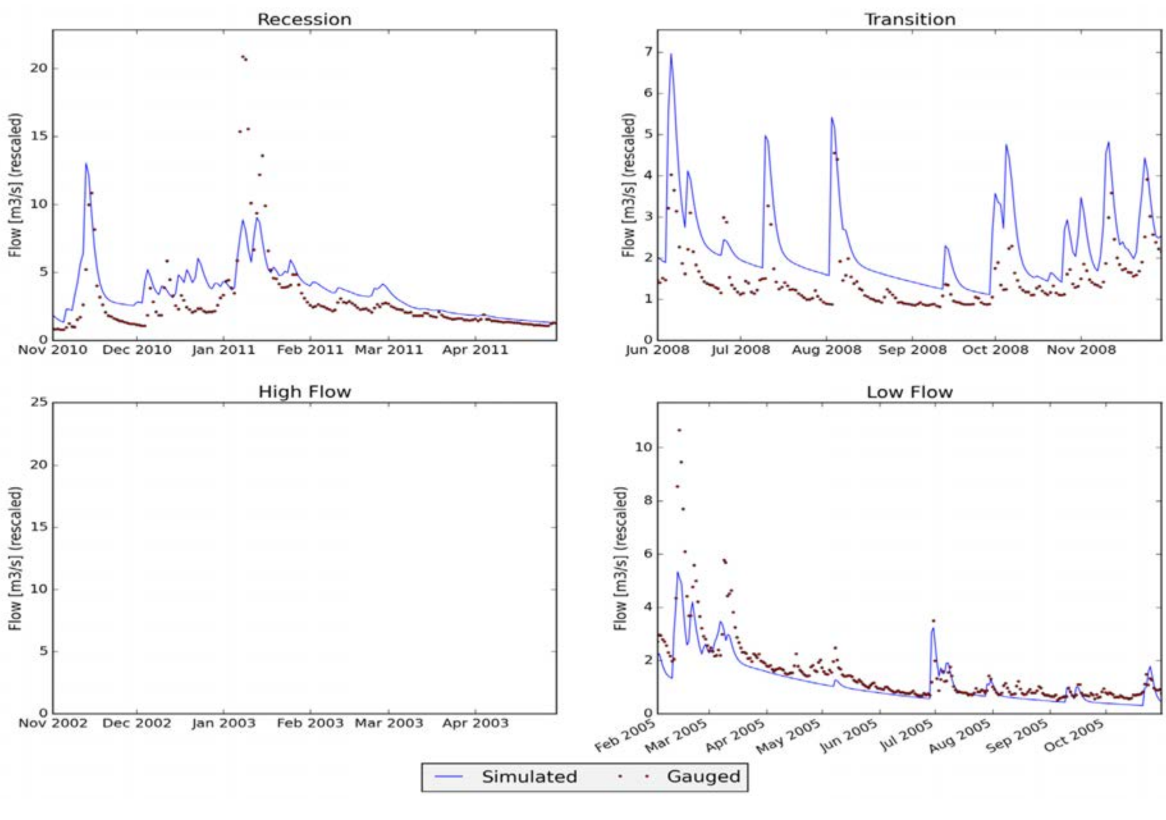


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11MEH5820, station Mehaigne, Wanze



Calibration and validation of NAM parameters for catchment "W11MAAPROF" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11MAAPROF (Meuse)

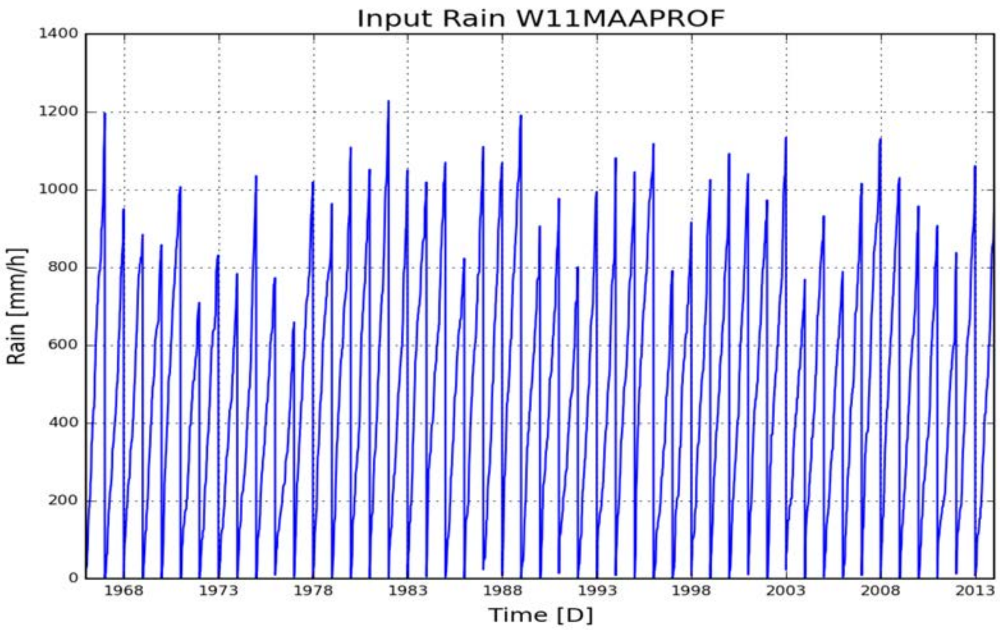
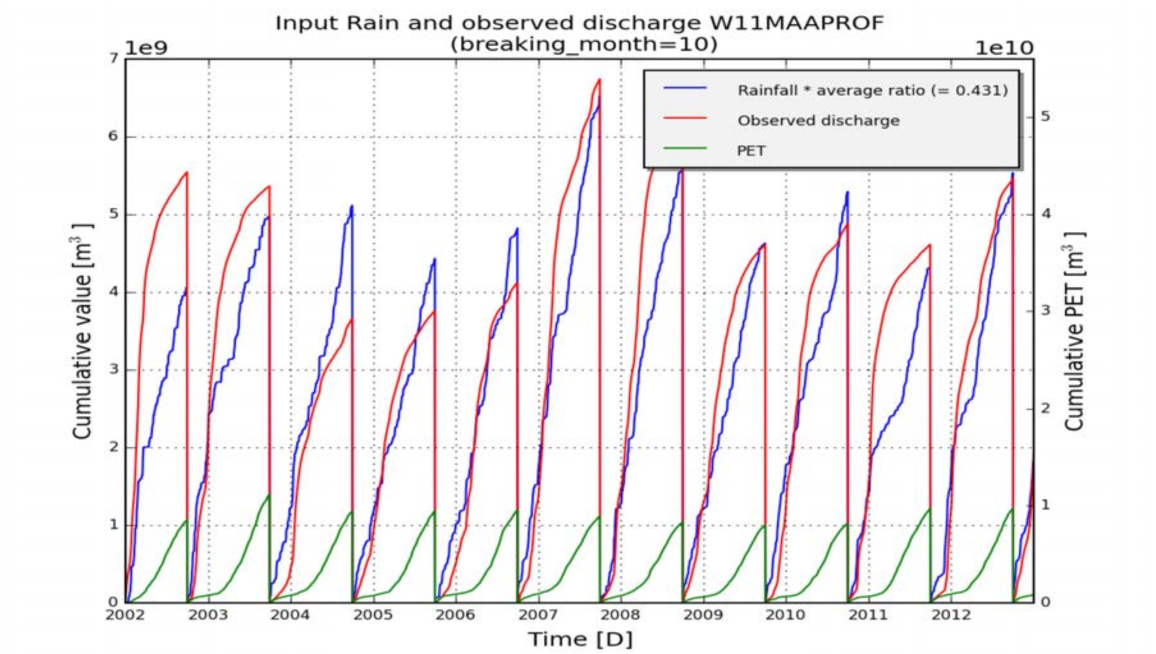


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11MAAPROF (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11MAAPROF
subcatchment_area [m^2]	12585000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2002 - 2012)

	Full year	**Summer**	**Winter**
RelErr	-0.6 %	-5.4 %	-2.8 %
NS	0.822	0.575	0.696
NS_log	0.84	0.466	0.715
NS_rel	0.874	0.817	0.663
KGE	0.84	0.614	0.698

Goodness of fit for validation period (all available period 2001 - 2012)

	Full year	**Summer**	**Winter**
RelErr	-8.0 %	-14.2 %	-6.2 %
NS	0.802	0.509	0.677
NS_log	0.824	0.337	0.714
NS_rel	0.869	0.778	0.664
KGE	0.805	0.578	0.675

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MAAPROF, station Meuse, Profondeville (complete simulation period 1967-2013)

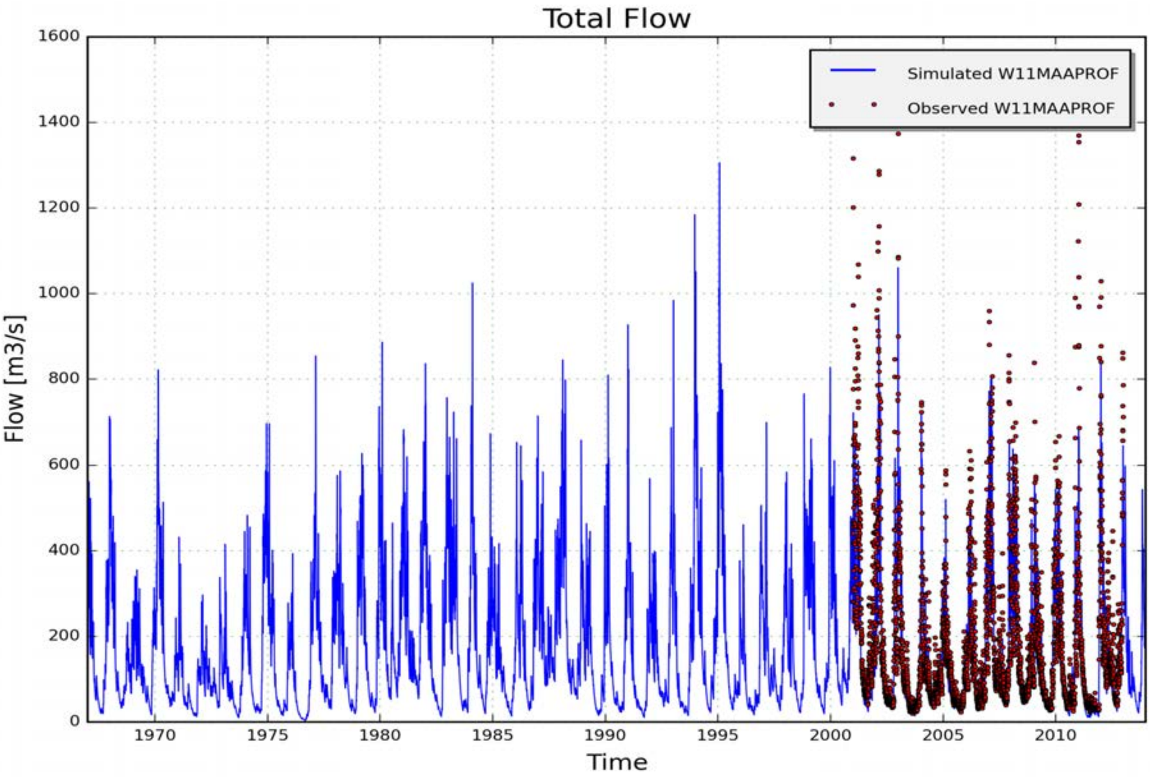


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MAAPROF, station Meuse, Profondeville(calibration period)

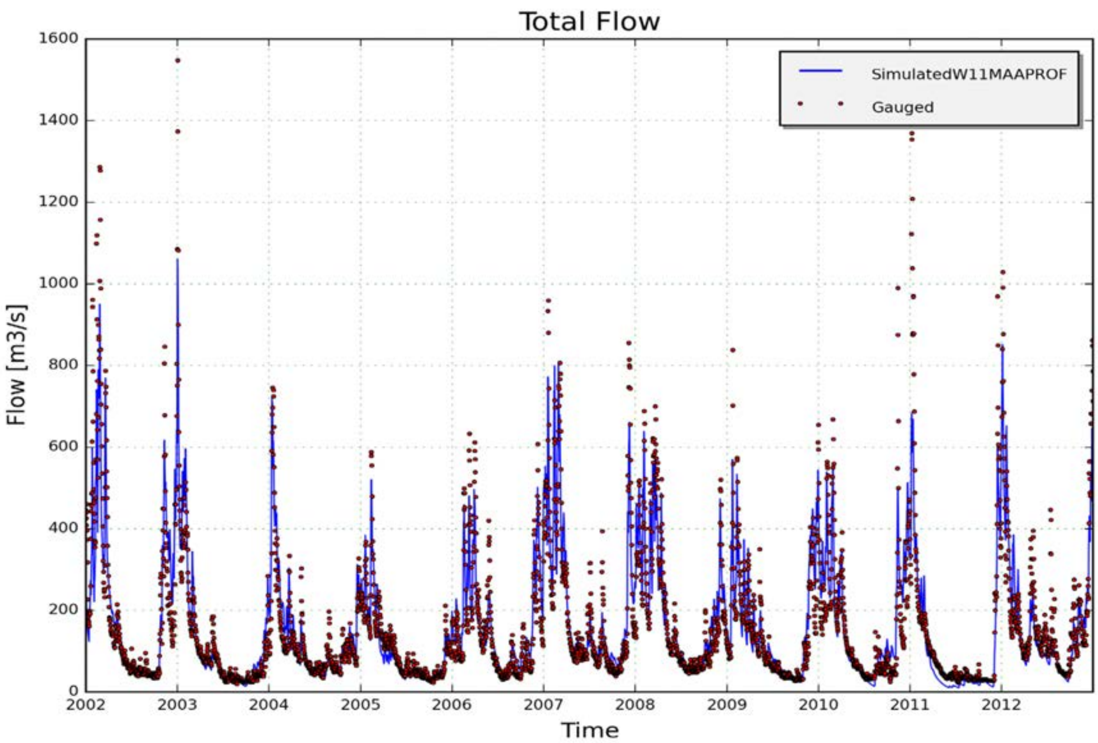


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11MAAPROF, station Meuse, Profondeville (calibration period)

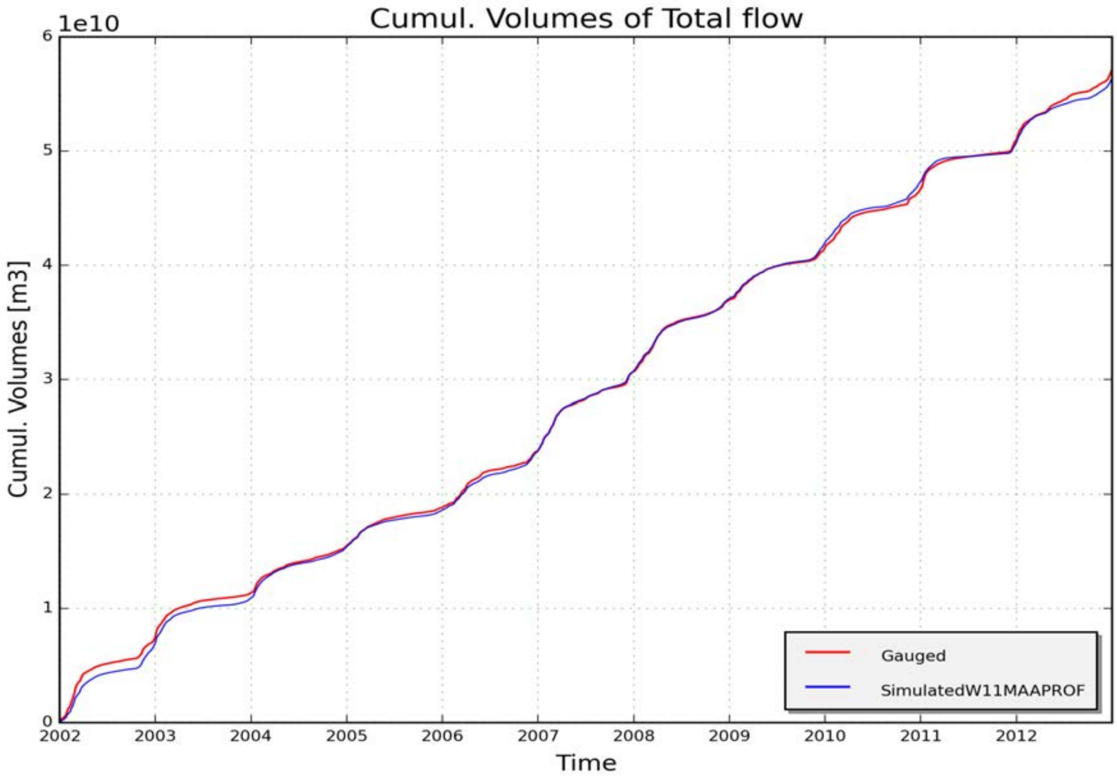
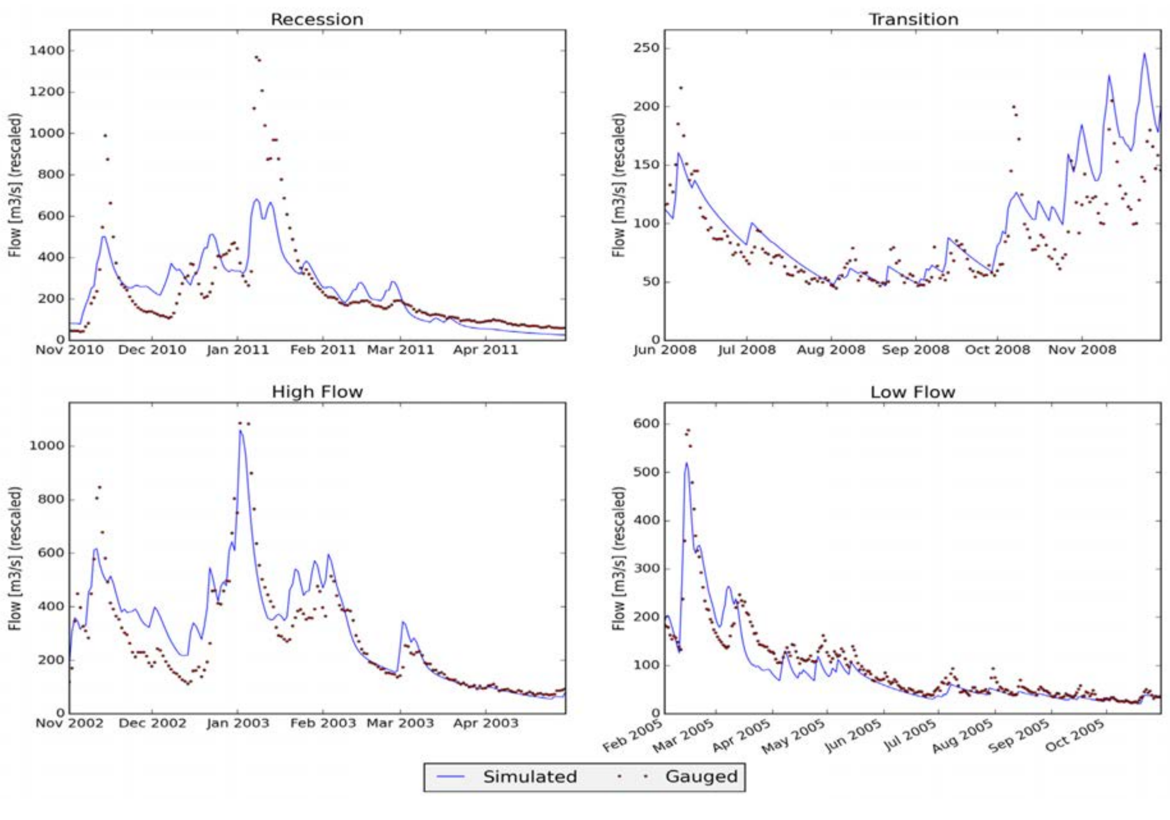


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11MAAPROF, station Meuse, Profondeville



Calibration and validation of NAM parameters for catchment "F11MAA8702" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment F11MAA8702 (Meuse)

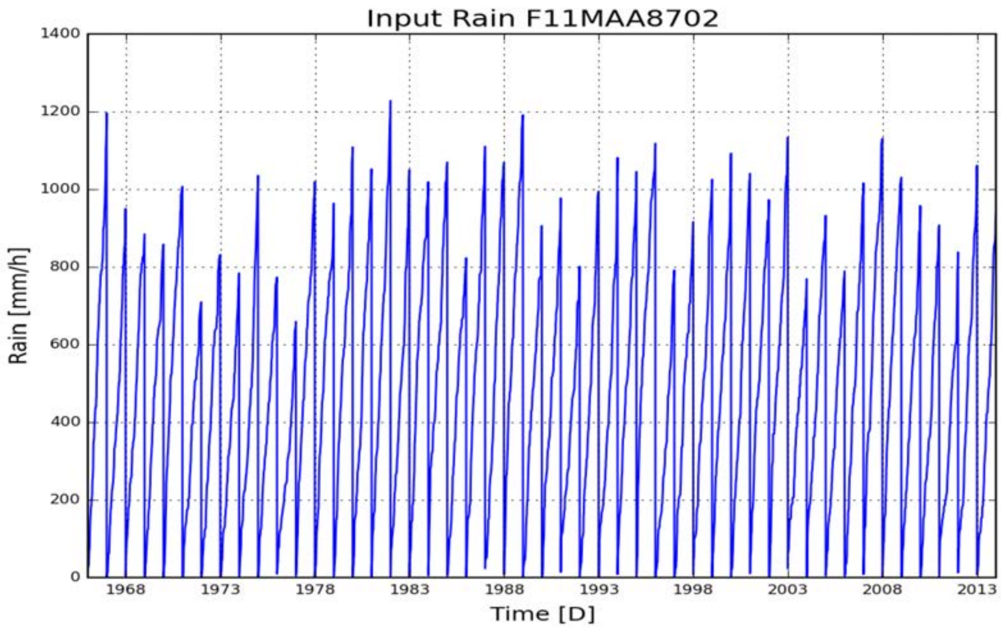
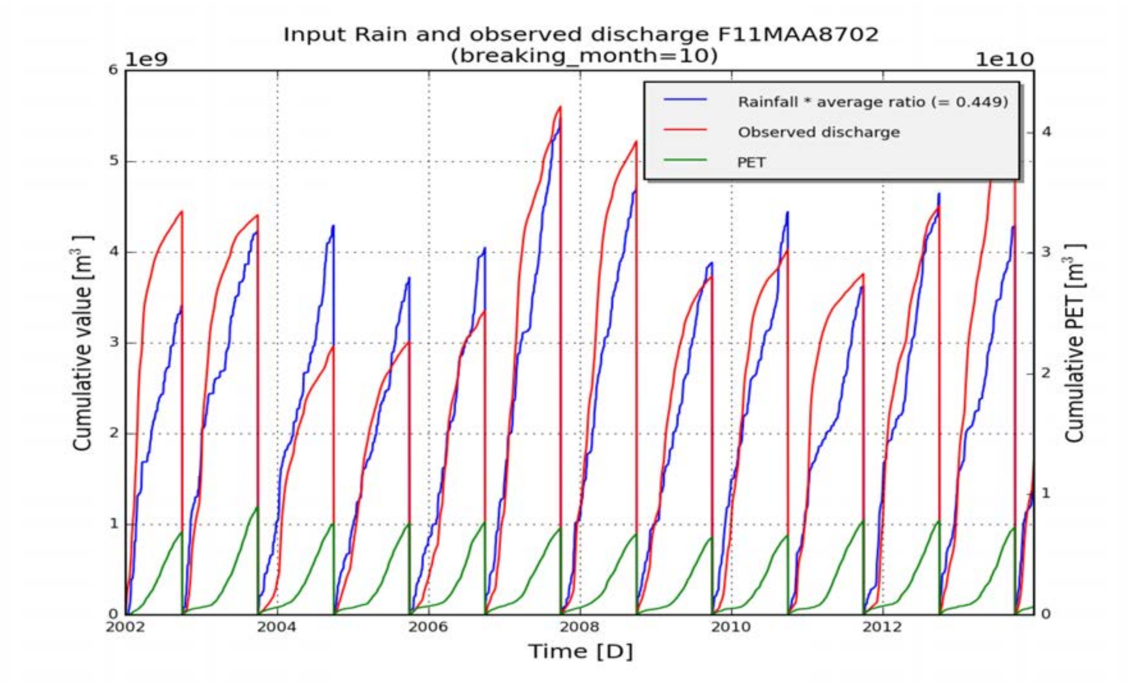


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment F11MAA8702 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	F11MAA8702
subcatchment_area [m^2]	10132000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2002 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-2.0 %	-6.4 %	-3.8 %
NS	0.802	0.524	0.673
NS_log	0.81	0.386	0.694
NS_rel	0.859	0.795	0.633
KGE	0.82	0.567	0.692

Goodness of fit for validation period (all available period 1990 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-5.5 %	-13.8 %	-5.5 %
NS	0.81	0.553	0.698
NS_log	0.823	0.375	0.695
NS_rel	0.857	0.779	0.579
KGE	0.793	0.599	0.668

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment F11MAA8702, station Meuse, Chooz (complete simulation period 1967-2013)

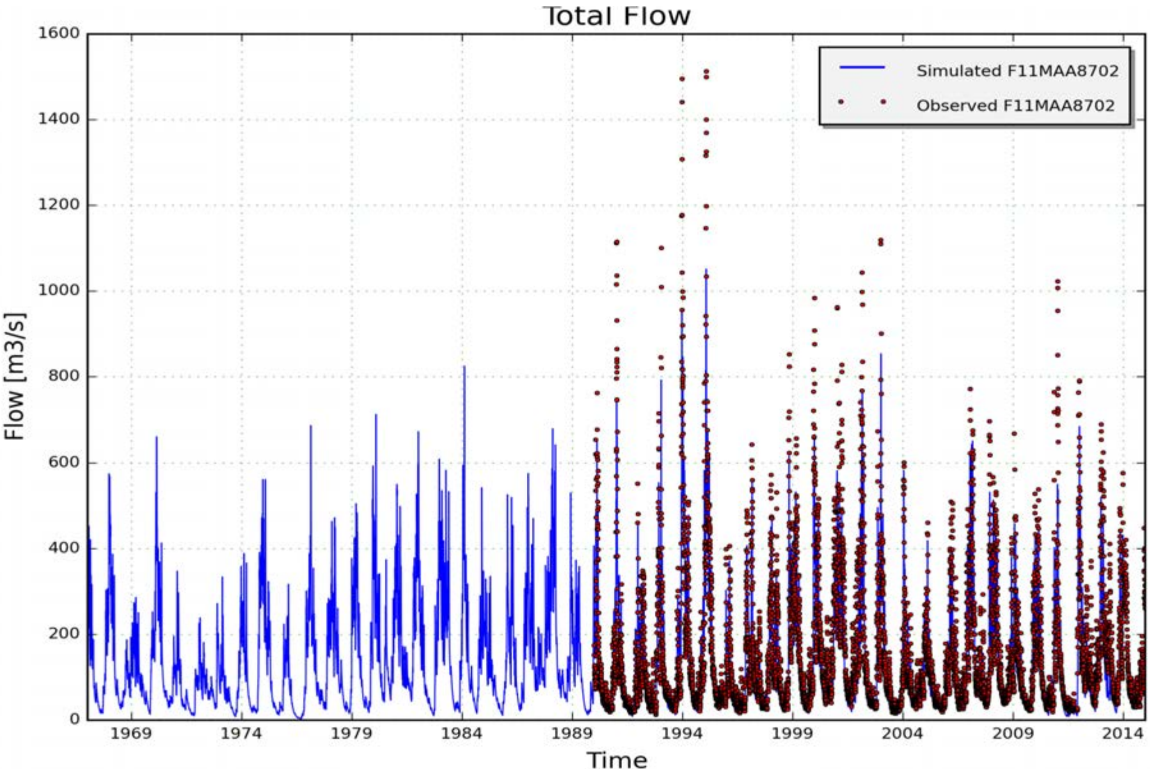


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment F11MAA8702, station Meuse, Chooz(calibration period)

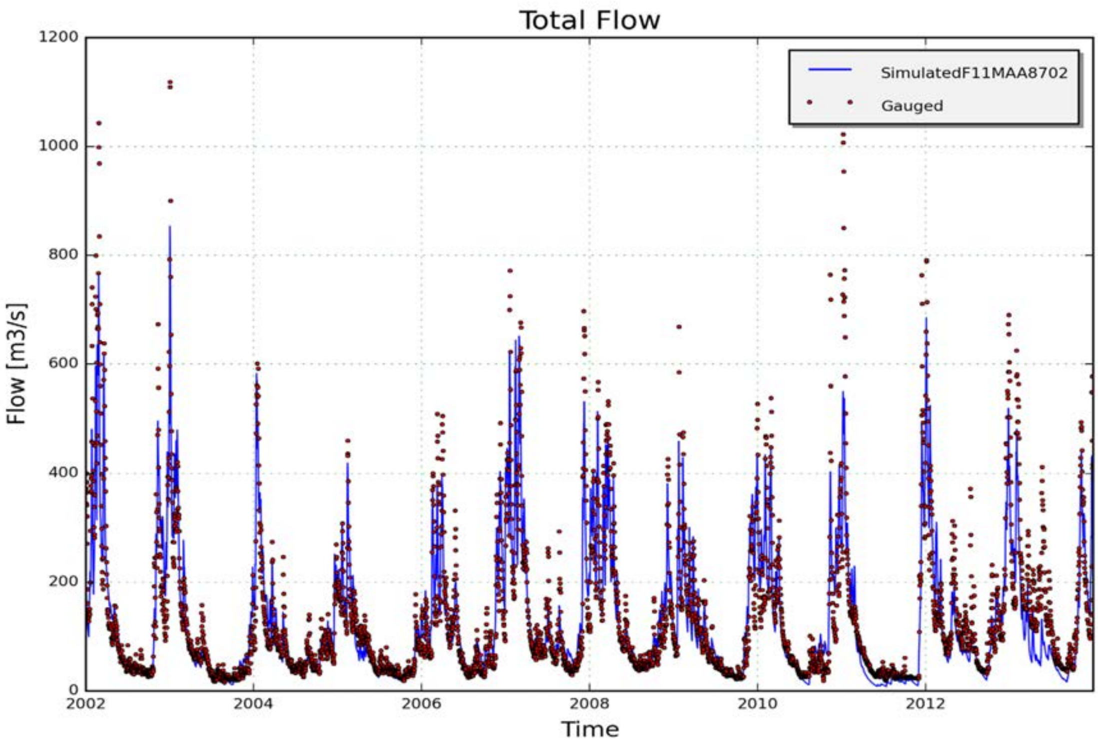


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment F11MAA8702, station Meuse, Chooz (calibration period)

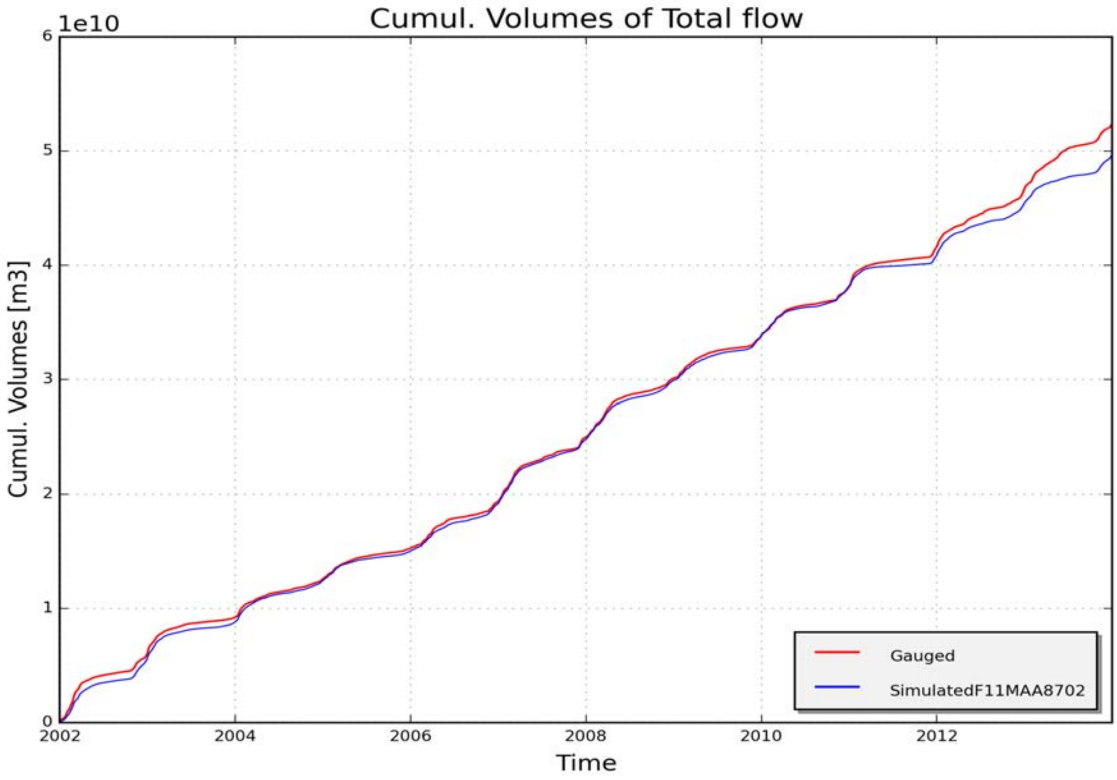
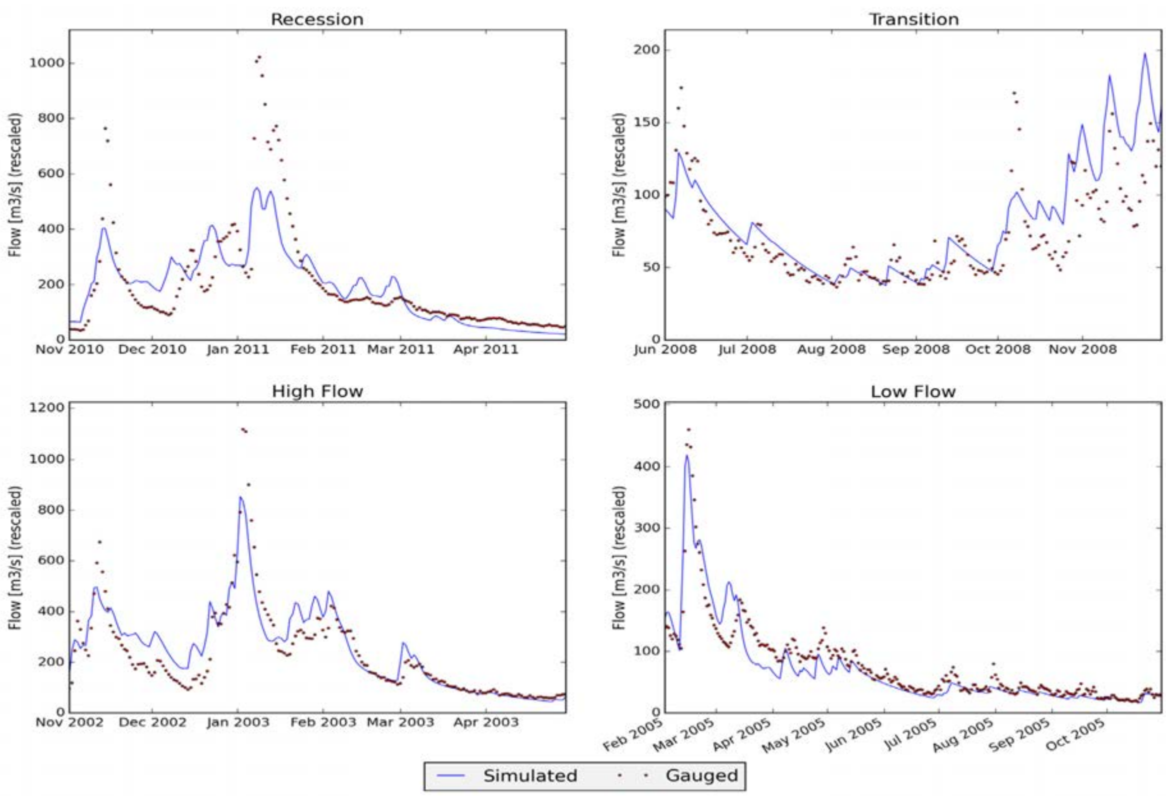


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment F11MAA8702, station Meuse, Chooz



Calibration and validation of NAM parameters for catchment "W11OUR5805" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11OUR5805 (Meuse)

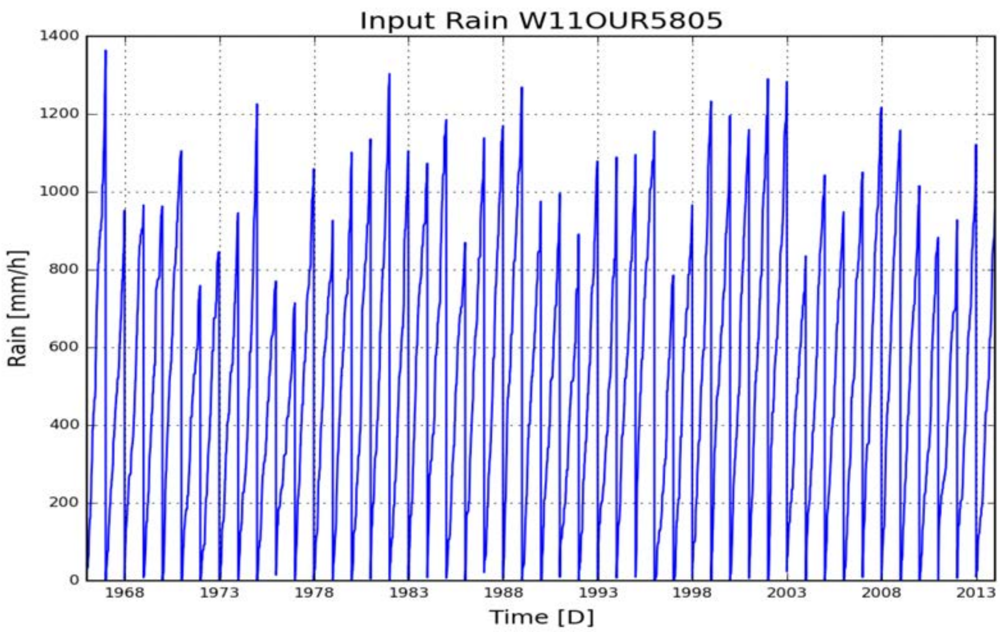
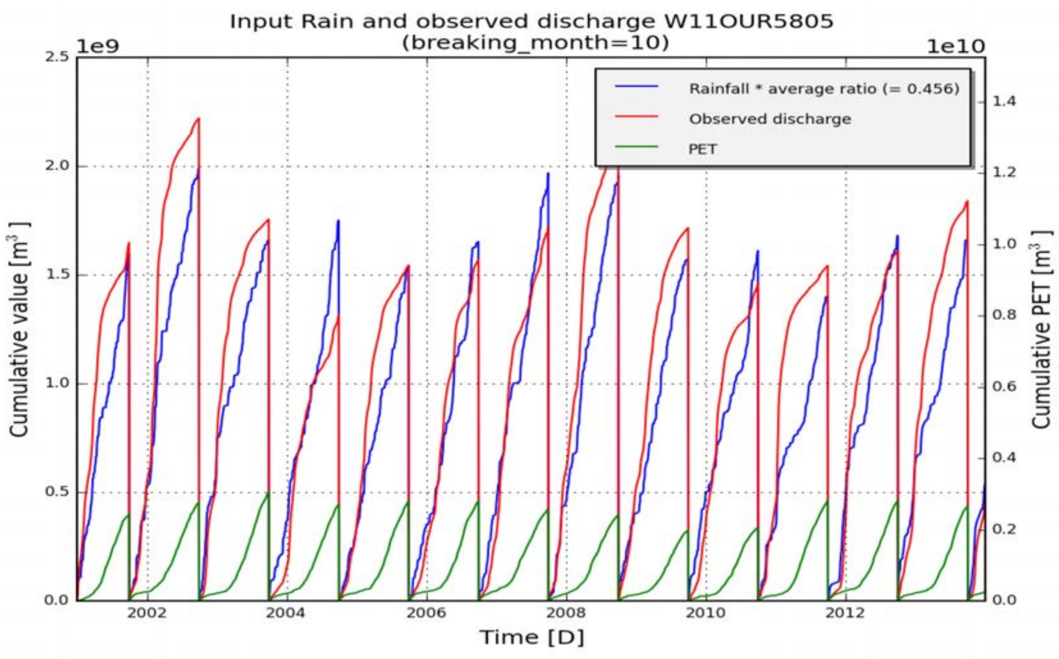


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11OUR5805 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11OUR5805
subcatchment_area [m^2]	3612000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 6.1), ('SMmax.C', 125.0), ('CQOF.C', 0.41), ('CKBF.C', 1794.0), ('CKIF.C', 200.4), ('CK1.C', 12.14), ('CK2.C', 75.48), ('TIF.C', 0.68), ('TOF.C', 0.36), ('NAM.TG.C', 0.43)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	0.3 %	5.1 %	-6.2 %
NS	0.778	0.655	0.666
NS_log	0.783	0.411	0.742
NS_rel	0.845	0.741	0.785
KGE	0.738	0.811	0.572

Goodness of fit for validation period (all available period 1974 - 2013)

	Full year	**Summer**	**Winter**
RelErr	2.1 %	2.3 %	-0.3 %
NS	0.77	0.727	0.669
NS_log	0.811	0.607	0.711
NS_rel	0.831	0.897	0.664
KGE	0.749	0.716	0.598

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11OUR5805, station Ourthe, Angleur 2 bis (complete simulation period 1967-2013)

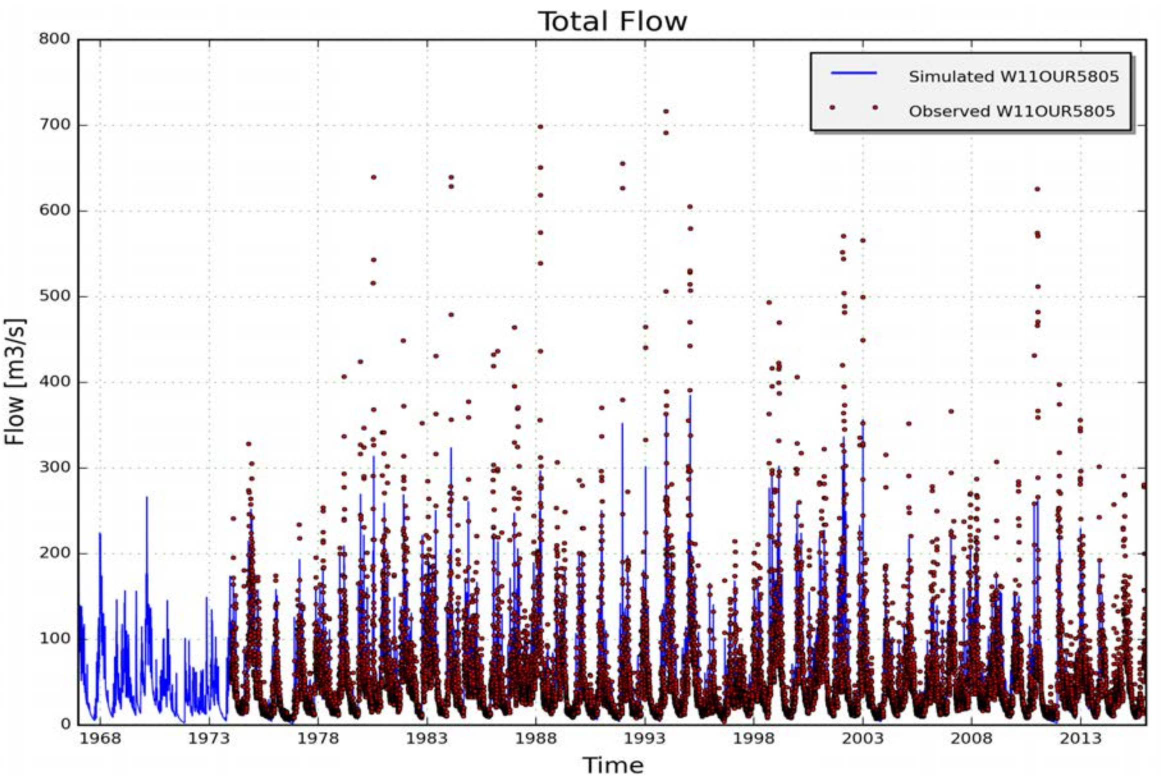


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11OUR5805, station Ourthe, Angleur 2 bis(calibration period)

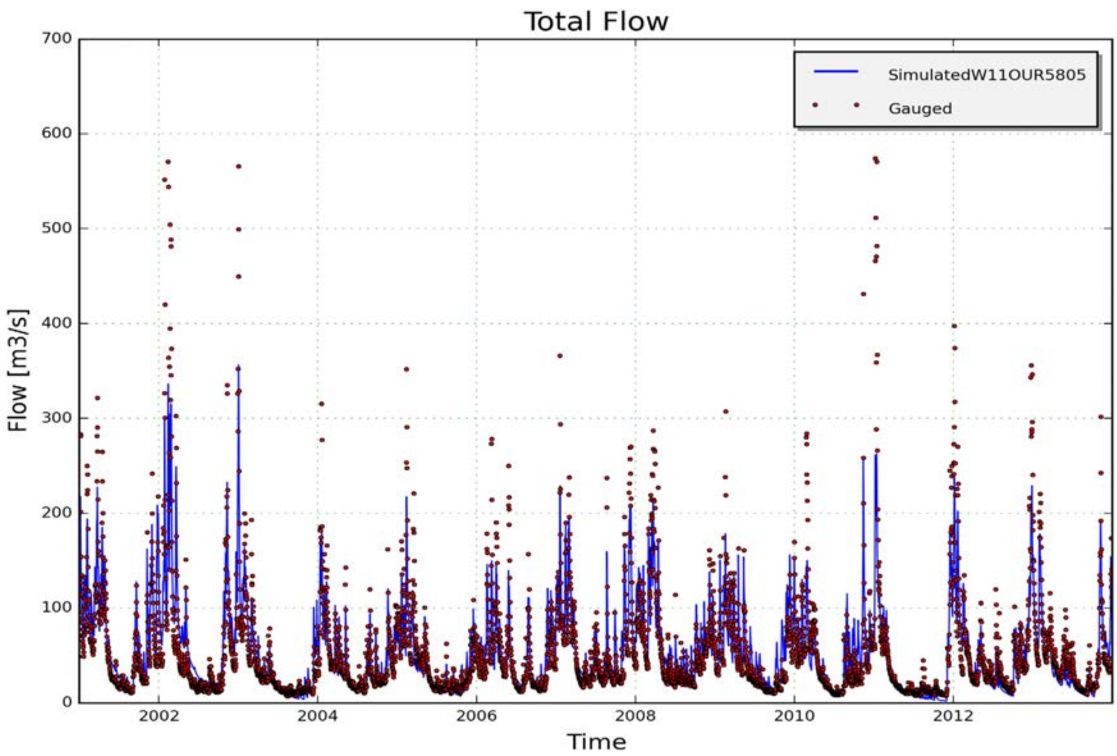


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11OUR5805, station Ourthe, Angleur 2 bis (calibration period)

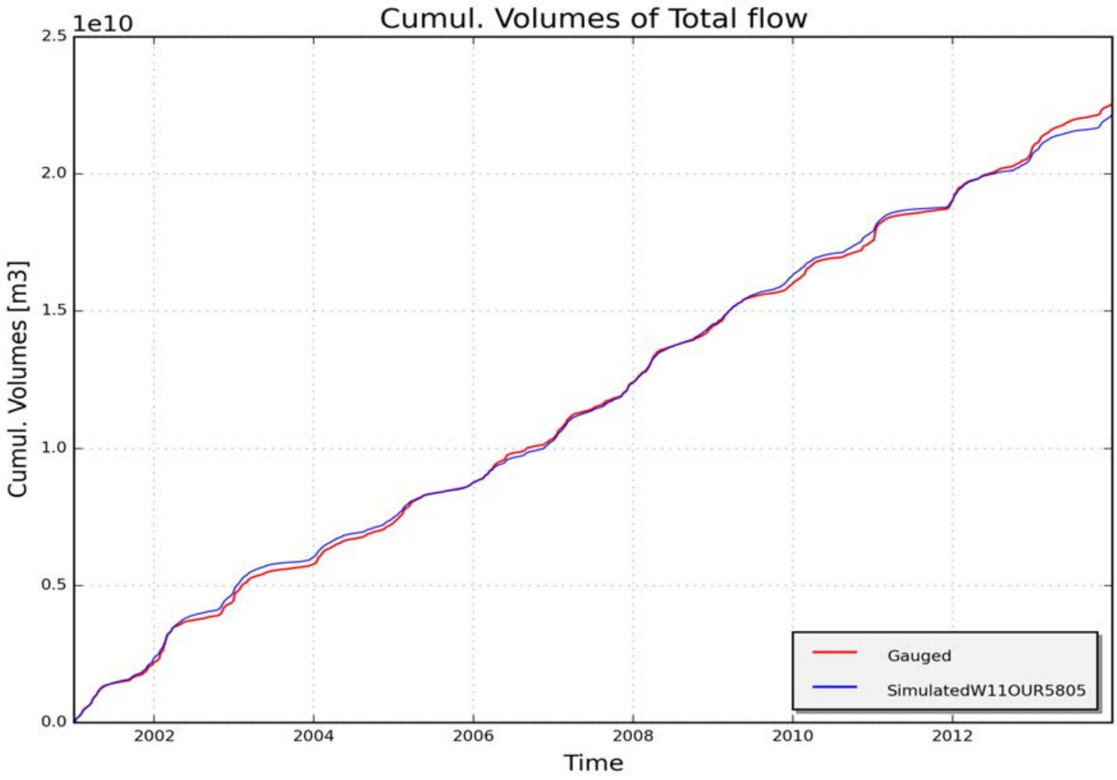
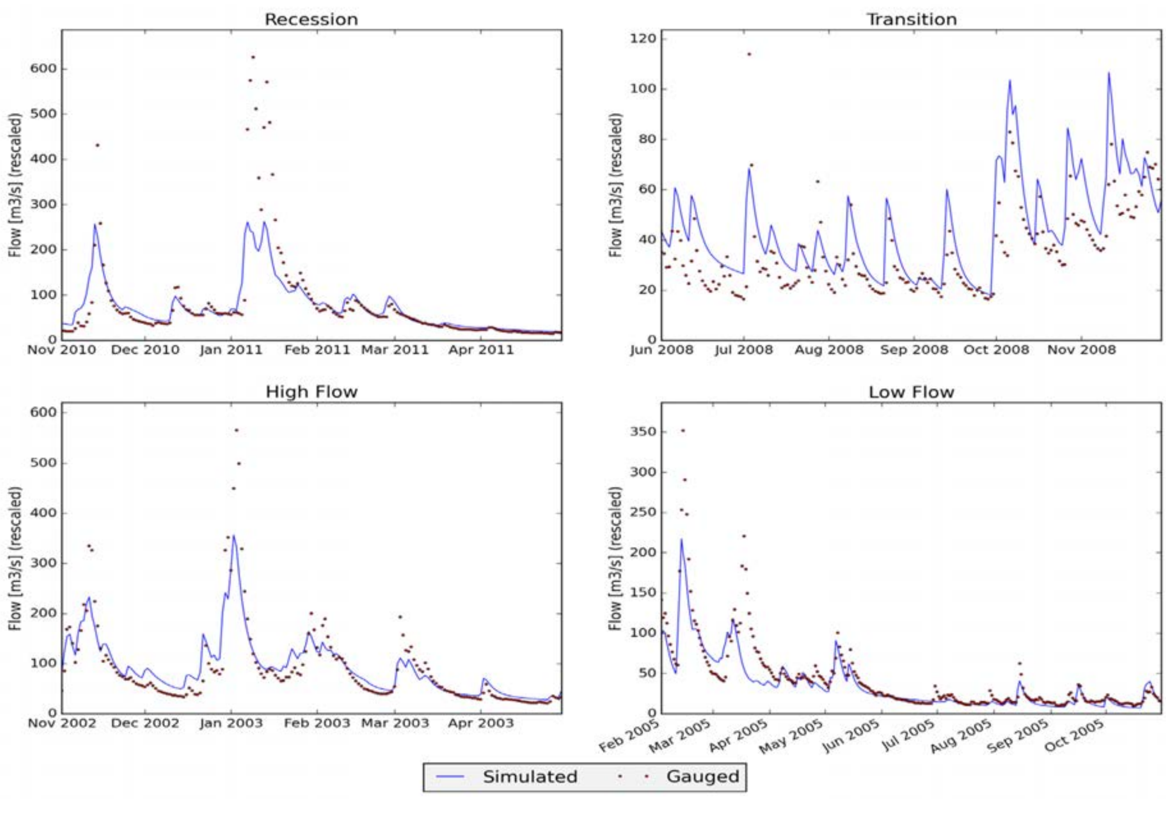


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11OUR5805, station Ourthe, Angleur 2 bis



Calibration and validation of NAM parameters for catchment "W11SAM7319" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11SAM7319 (Meuse)

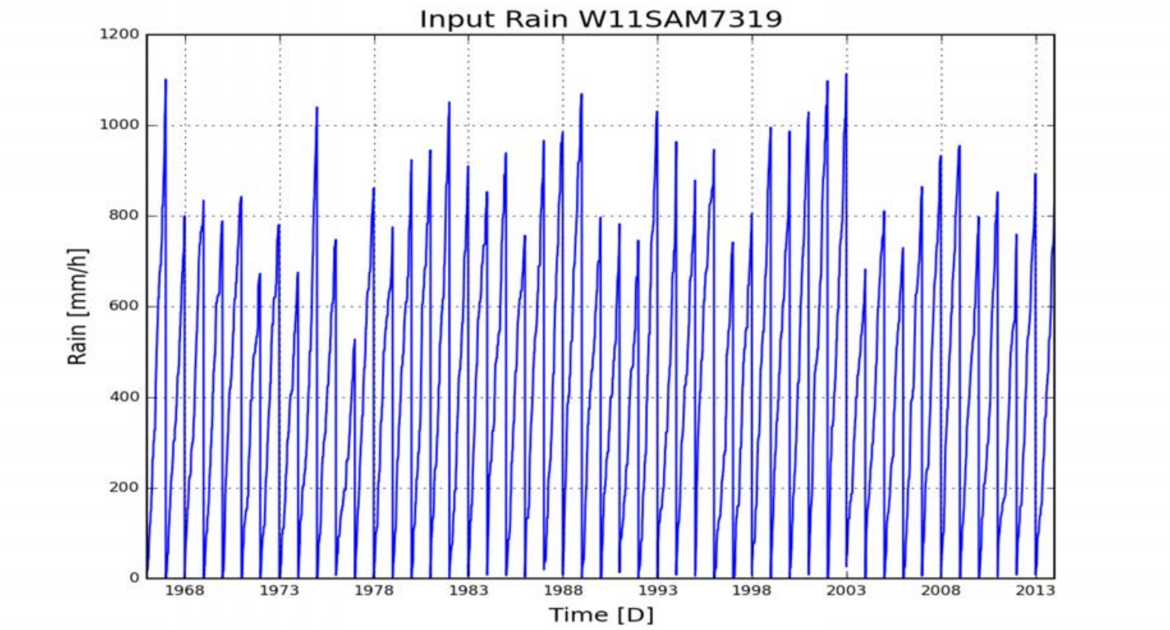
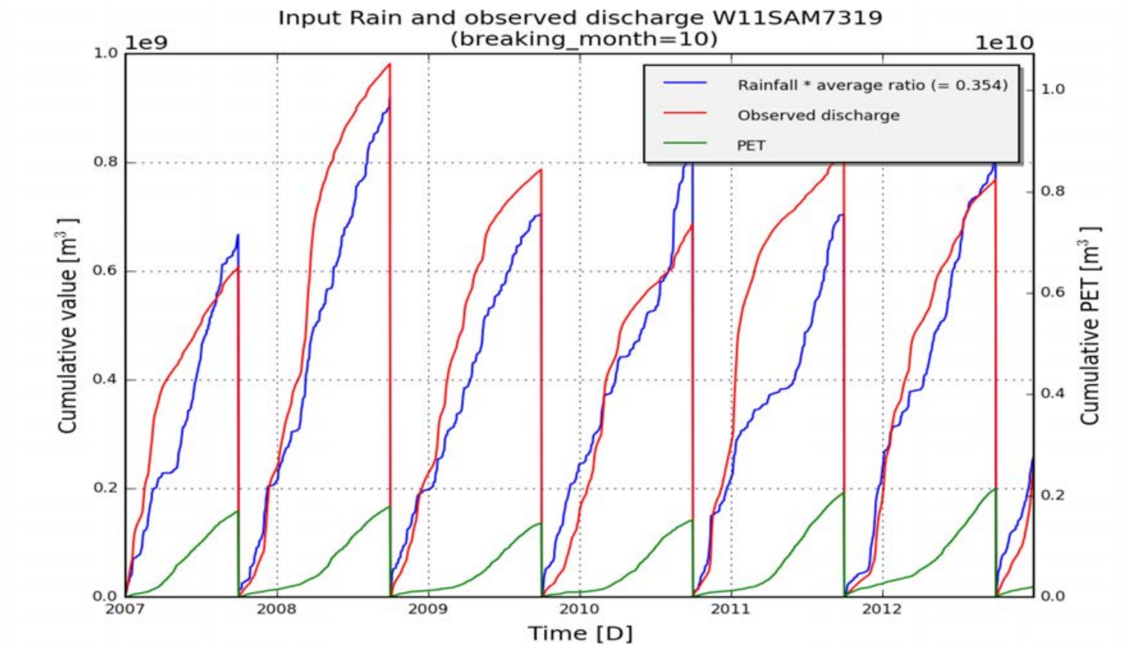


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11SAM7319 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11SAM7319
subcatchment_area [m²]	2669000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2007 - 2012)

	Full year	Summer	Winter
RelErr	6.2 %	40.5 %	-12.3 %
NS	0.703	0.014	0.609
NS_log	0.697	0.033	0.733
NS_rel	0.693	0.044	0.802
KGE	0.659	0.495	0.496

Goodness of fit for validation period (all available period 2007 - 2013)

	Full year	Summer	Winter
RelErr	3.5 %	35.4 %	-14.6 %
NS	0.684	0.085	0.558
NS_log	0.694	0.082	0.677
NS_rel	0.719	0.123	0.793
KGE	0.639	0.549	0.463

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11SAM7319, station Samber, Salzinne (complete simulation period 1967-2013)

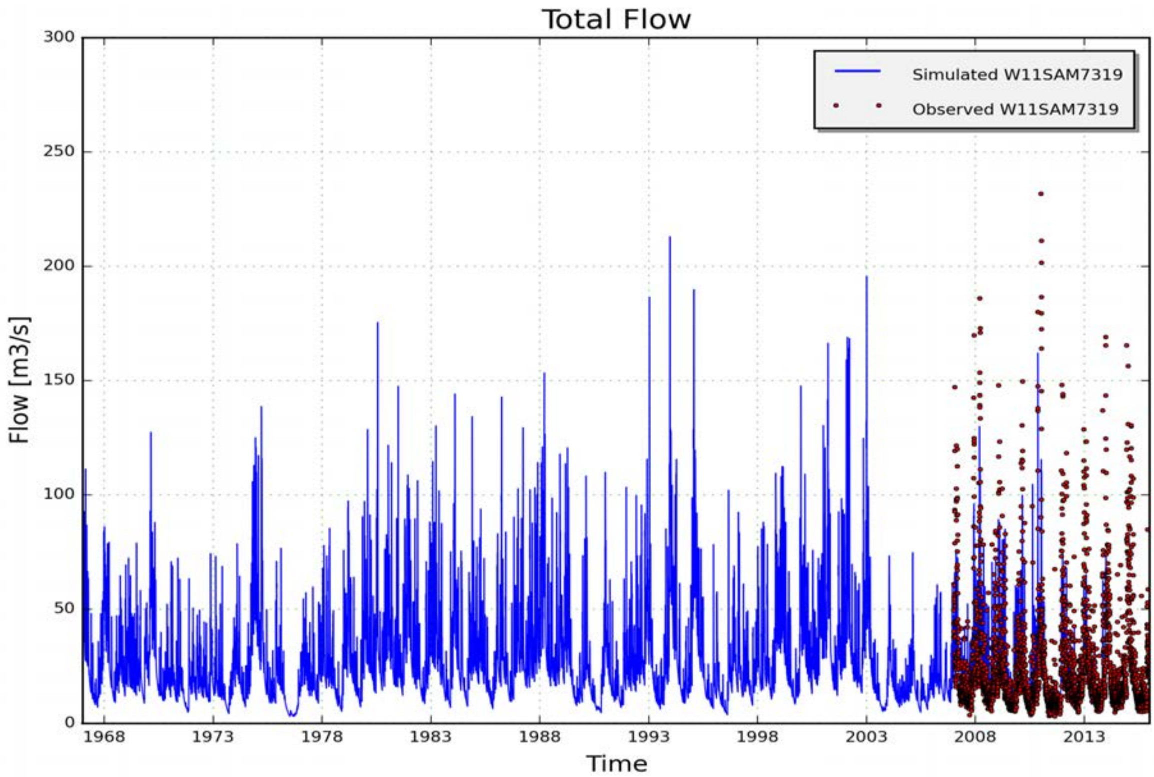


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11SAM7319, station Samber, Salzinne(calibration period)

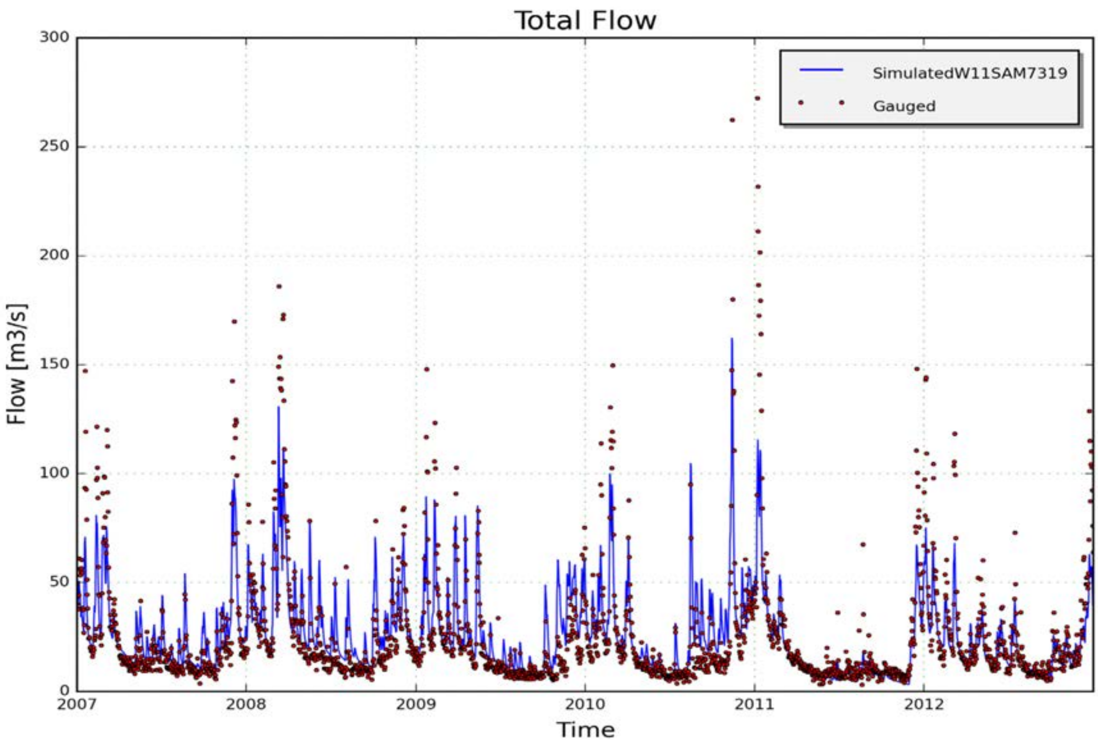


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11SAM7319, station Samber, Salzinne (calibration period)

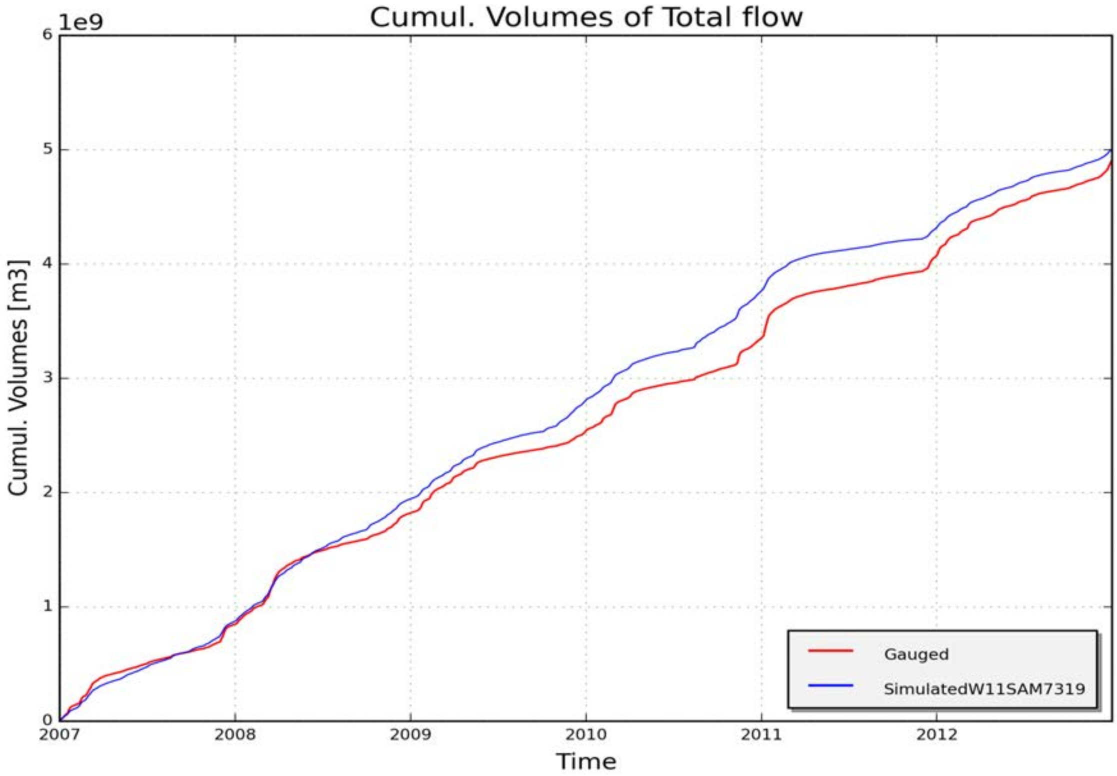


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11SAM7319, station Samber, Salzinne

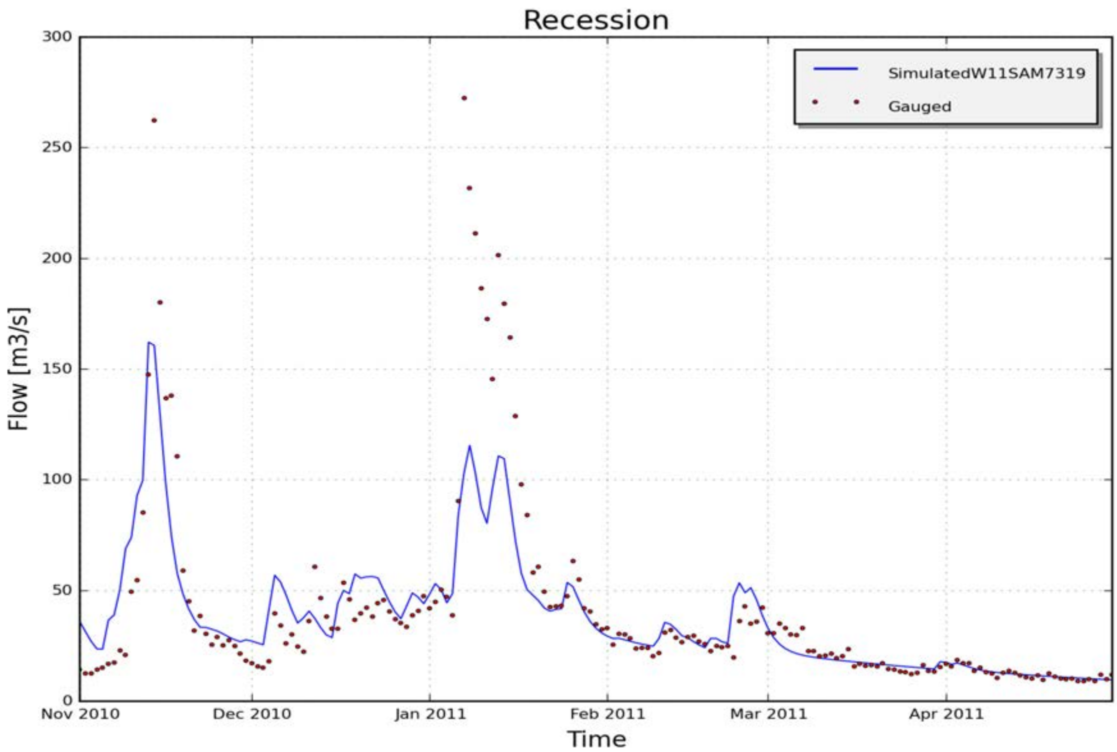
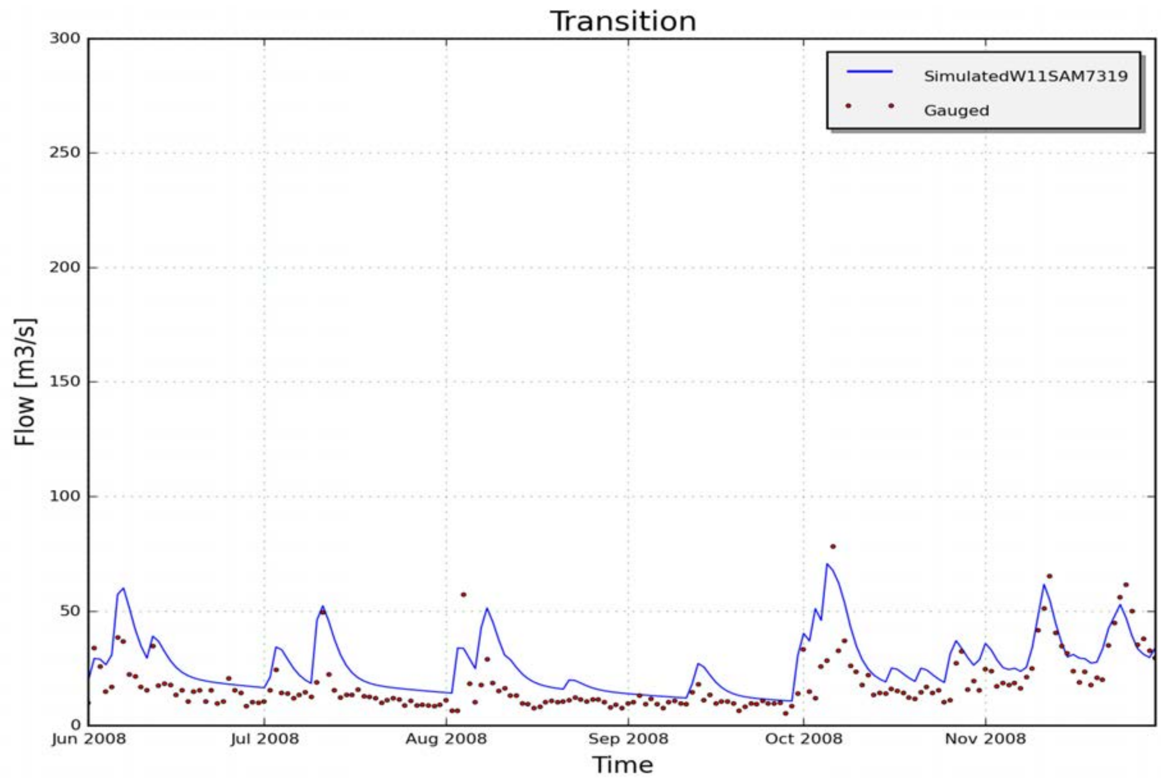


Figure 7 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11SAM7319, station Samber, Salzinne



Calibration and validation of NAM parameters for catchment "W11BER551010" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11BER551010 (Meuse)

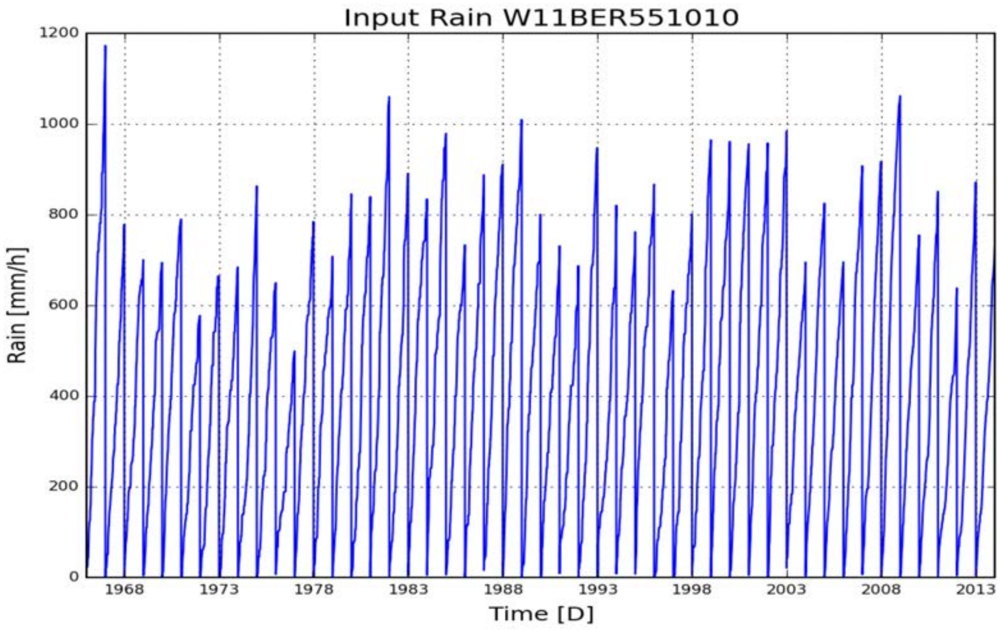
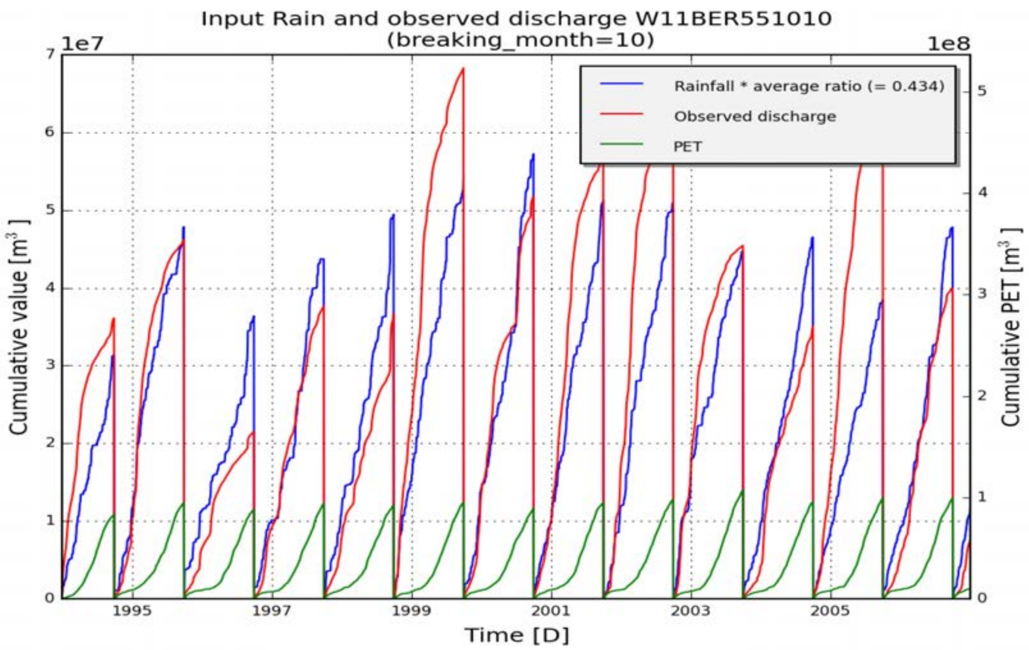


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11BER551010 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11BER551010
subcatchment_area [m^2]	128000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 2.25), ('SMmax.C', 193.0), ('CQOF.C', 0.75), ('CKBF.C', 1606.0), ('CKIF.C', 460.0), ('CK1.C', 46.0), ('CK2.C', 55.0), ('TIF.C', 0.9), ('TOF.C', 0.17), ('NAM.TG.C', 0.13)]

Goodness of fit for calibration period (1994 - 2006)

	Full year	**Summer**	**Winter**
RelErr	-0.7 %	1.7 %	-6.4 %
NS	0.62	0.546	0.576
NS_log	0.624	0.293	0.688
NS_rel	0.678	0.737	0.669
KGE	0.638	0.603	0.595

Goodness of fit for validation period (all available period 1991 - 2013)

	Full year	**Summer**	**Winter**
RelErr	3.7 %	17.2 %	-5.3 %
NS	0.506	0.305	0.482
NS_log	0.26	-0.391	0.449
NS_rel	-13.984	-16.993	-3.377
KGE	0.588	0.53	0.524

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BER551010, station unkown (complete simulation period 1967-2013)

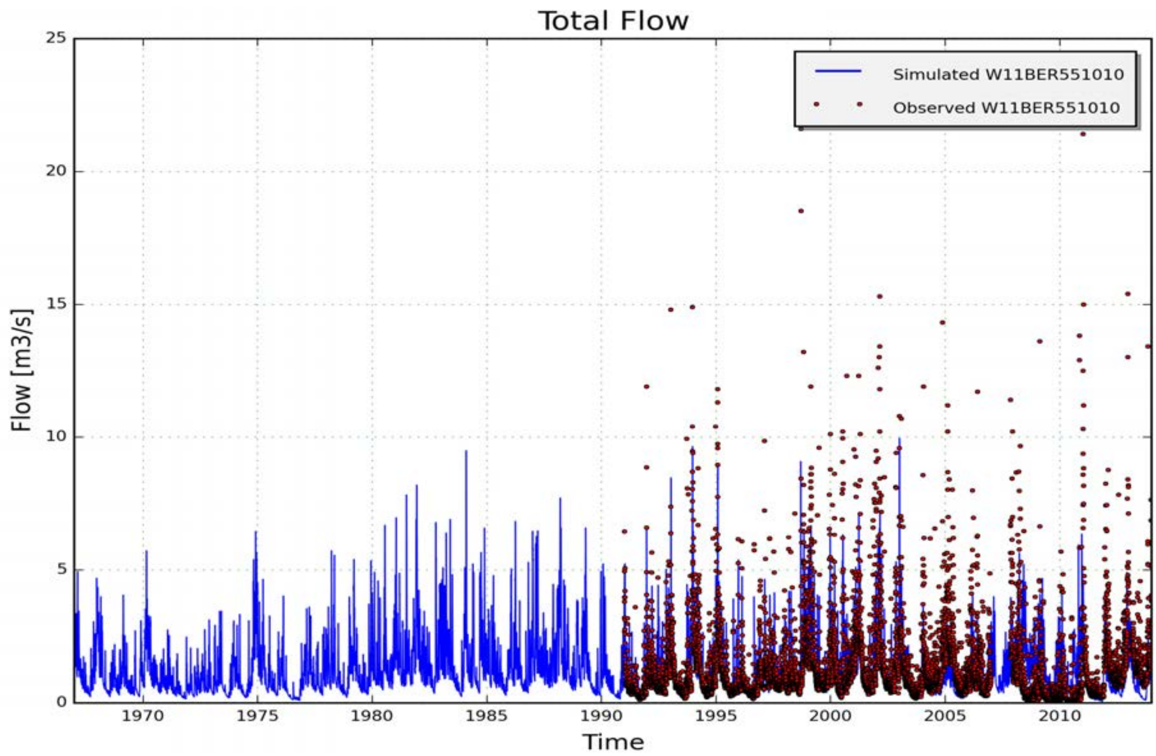


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BER551010, station unkown(calibration period)

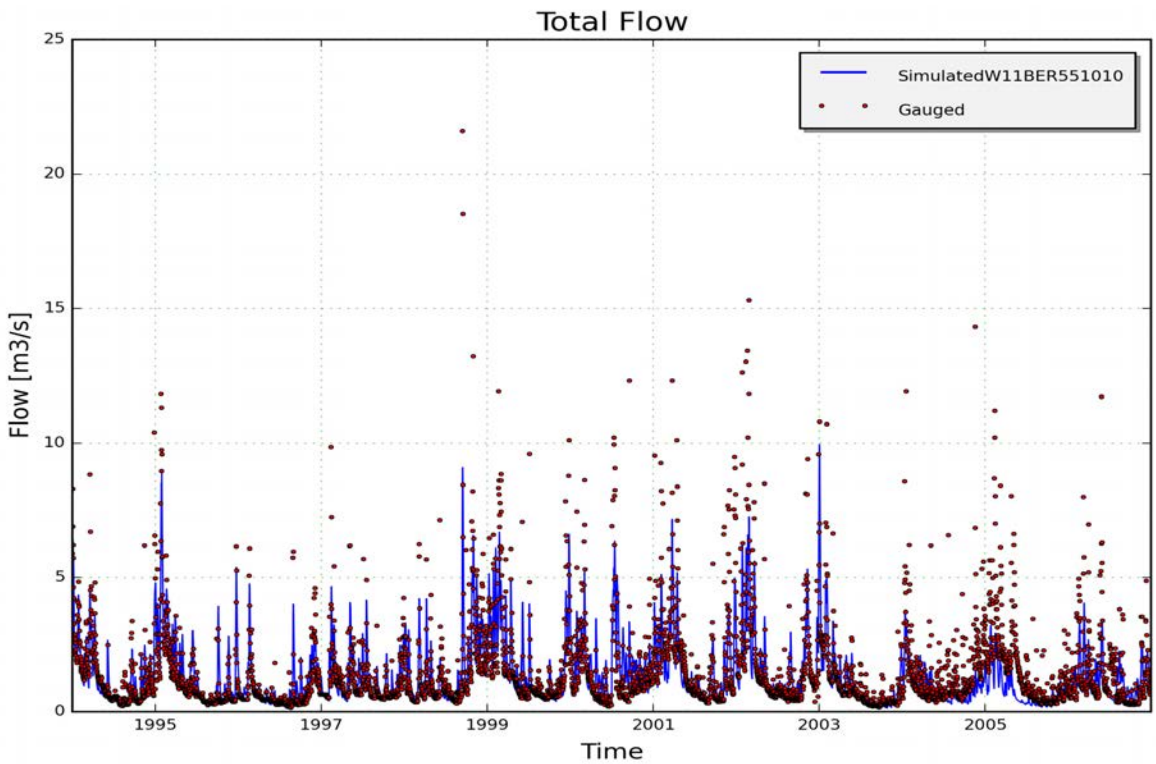


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11BER551010, station unkown (calibration period)

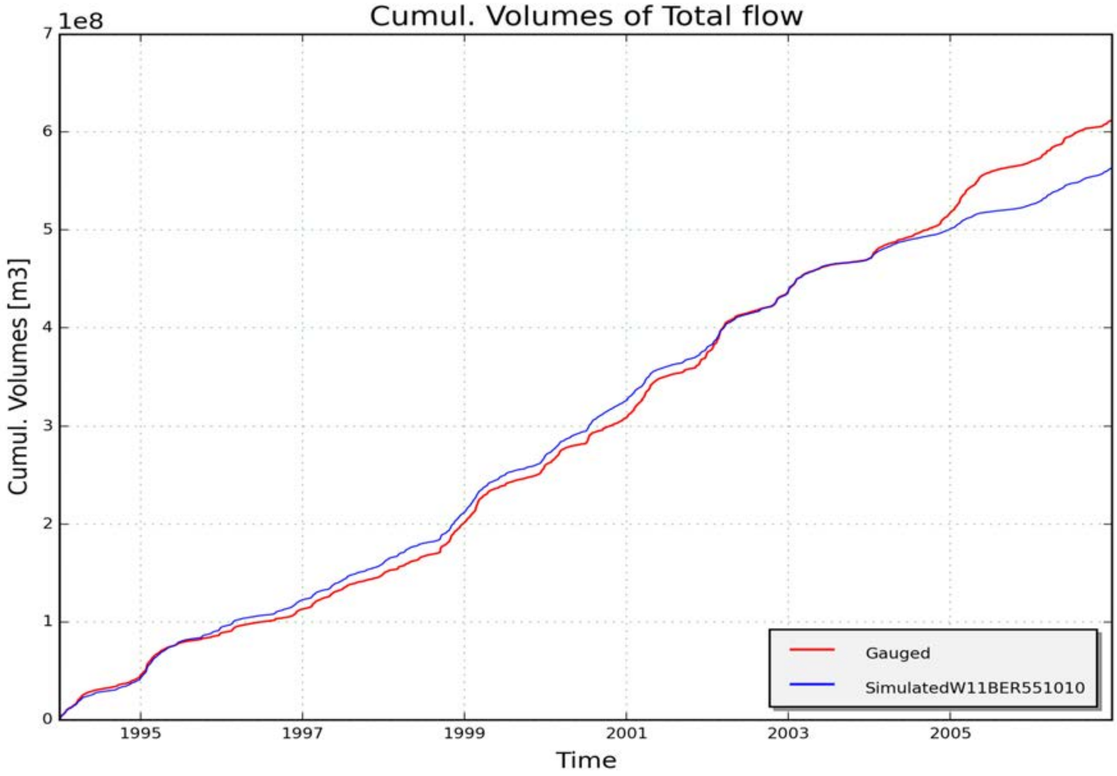


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11BER551010, station unkown

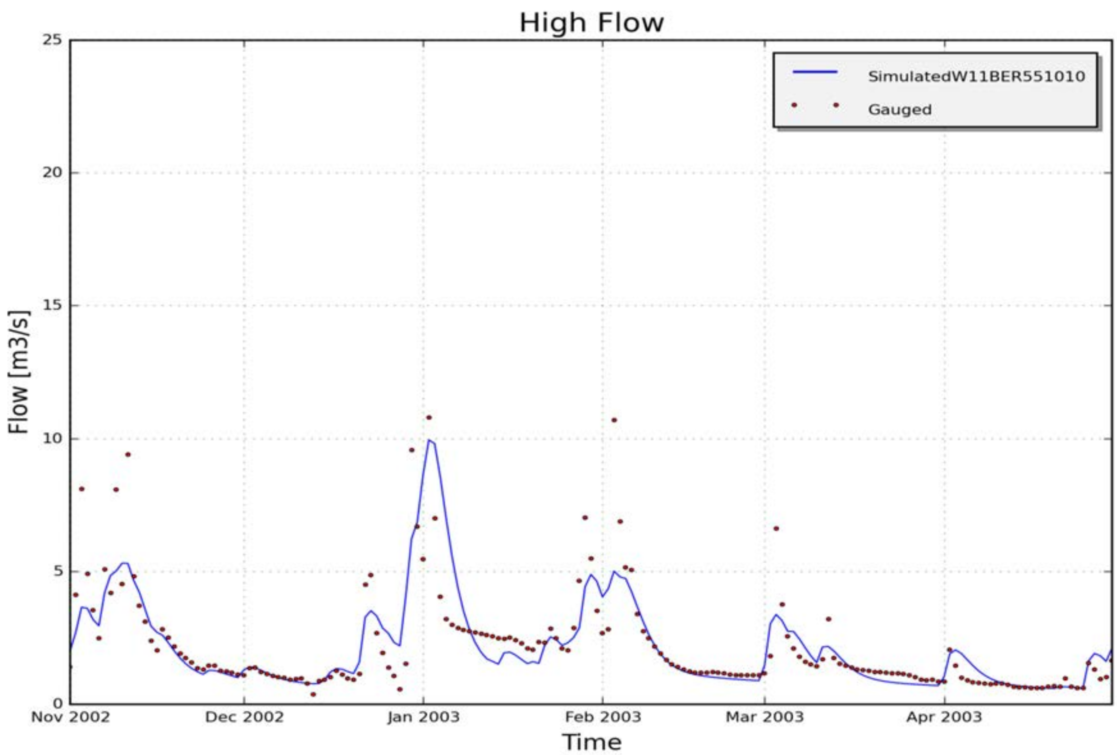
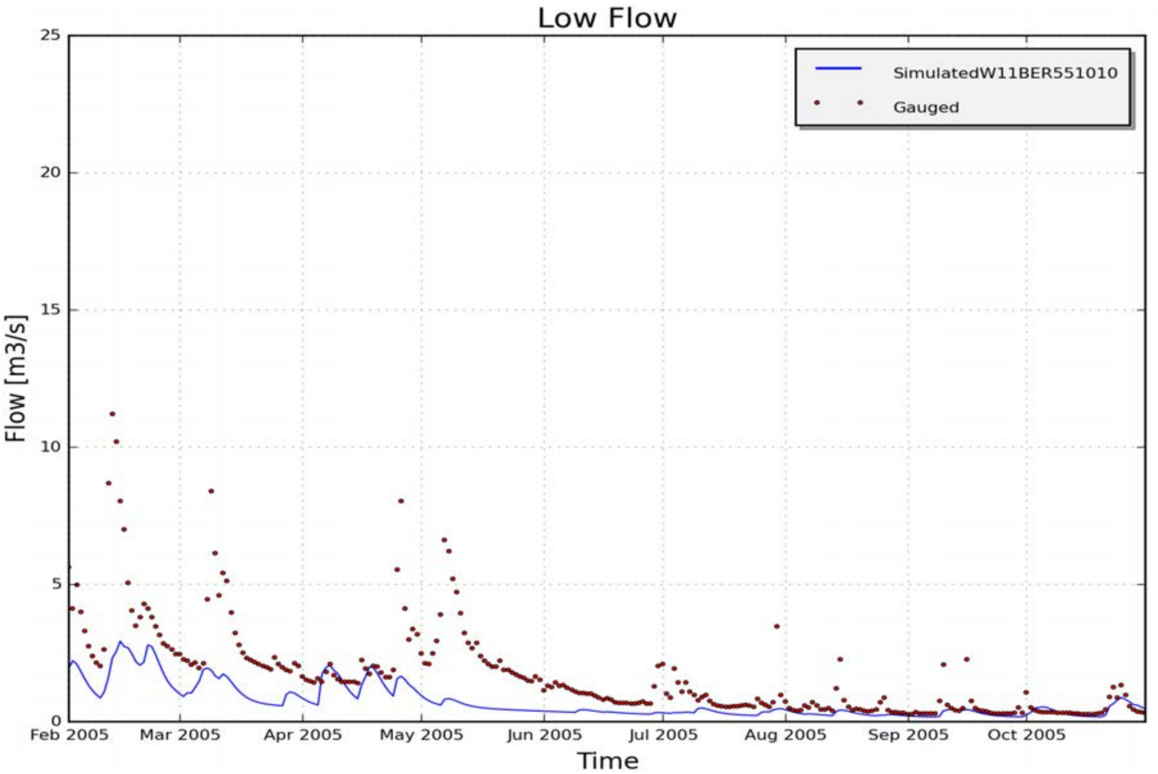


Figure 7 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11BER551010, station unkown



Calibration and validation of NAM parameters for catchment "W11JEK553010" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11JEK553010 (Meuse)

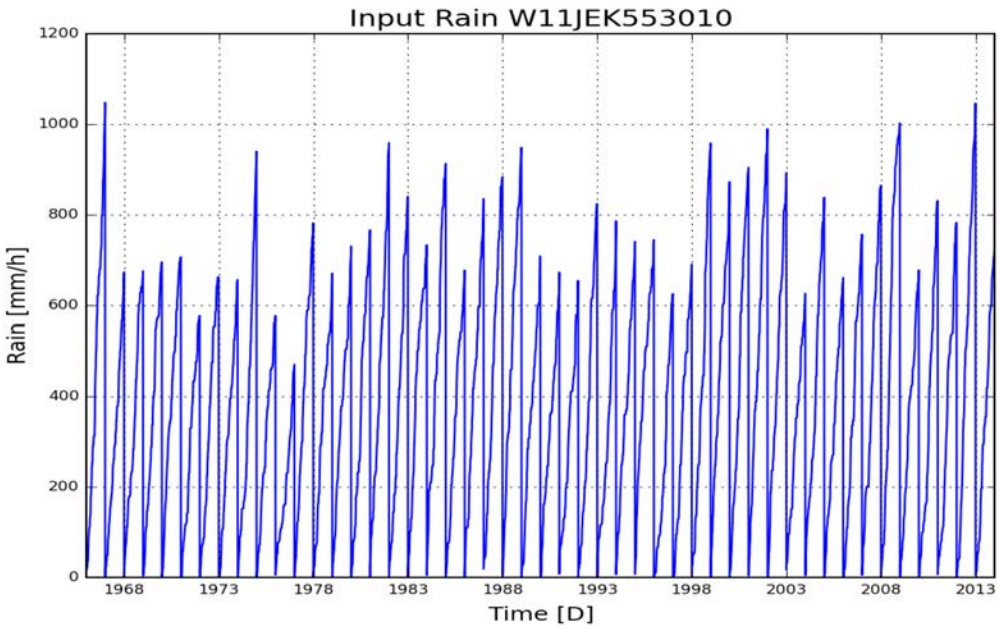
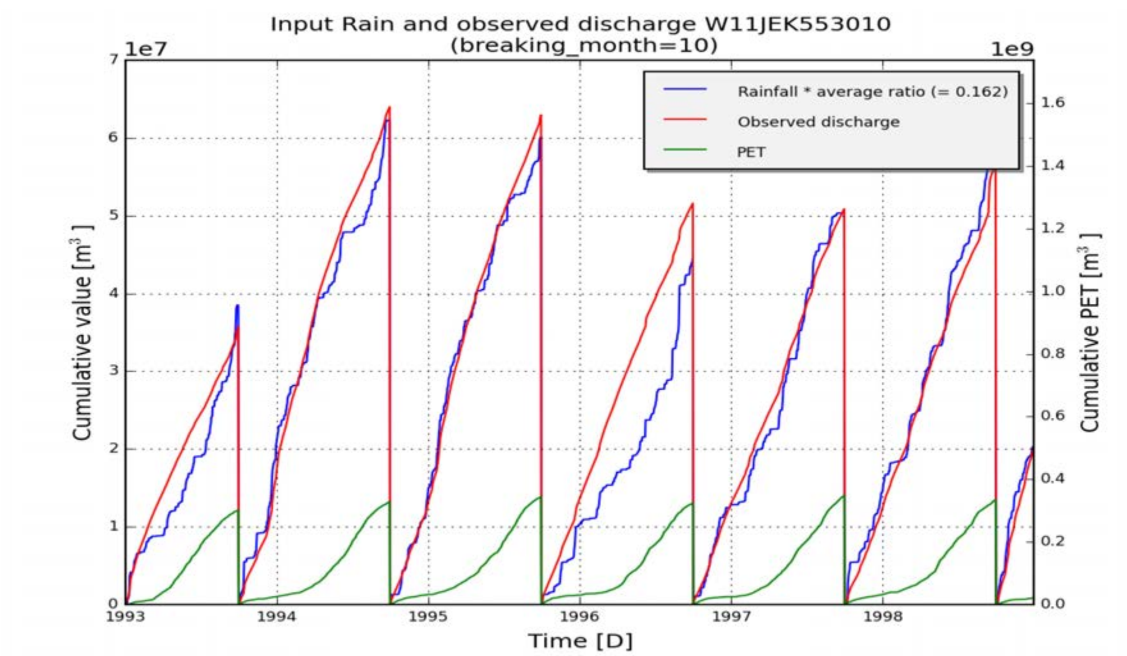


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11JEK553010 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11JEK553010
subcatchment_area [m²]	465499442
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 5.0), ('SMmax.C', 300.0), ('CQOF.C', 0.1), ('CKBF.C', 2000.0), ('CKIF.C', 1000.0), ('CK1.C', 72.0), ('CK2.C', 72.0), ('TIF.C', 0.1), ('TOF.C', 0.3), ('NAM.TG.C', 0.2)]

Goodness of fit for calibration period (1993 - 1998)

	Full year	**Summer**	**Winter**
RelErr	88.2 %	30.2 %	136.2 %
NS	-4.214	-0.09	-8.213
NS_log	-2.959	-1.66	-4.146
NS_rel	-3.462	0.21	-8.583
KGE	-0.398	0.336	-0.743

Goodness of fit for validation period (all available period 1993 - 2013)

	Full year	**Summer**	**Winter**
RelErr	66.7 %	35.0 %	94.2 %
NS	-3.424	-1.858	-4.007
NS_log	-2.074	-1.565	-2.399
NS_rel	-4.351	-2.179	-5.776
KGE	-0.161	0.052	-0.124

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11JEK553010, station unkown (complete simulation period 1967-2013)

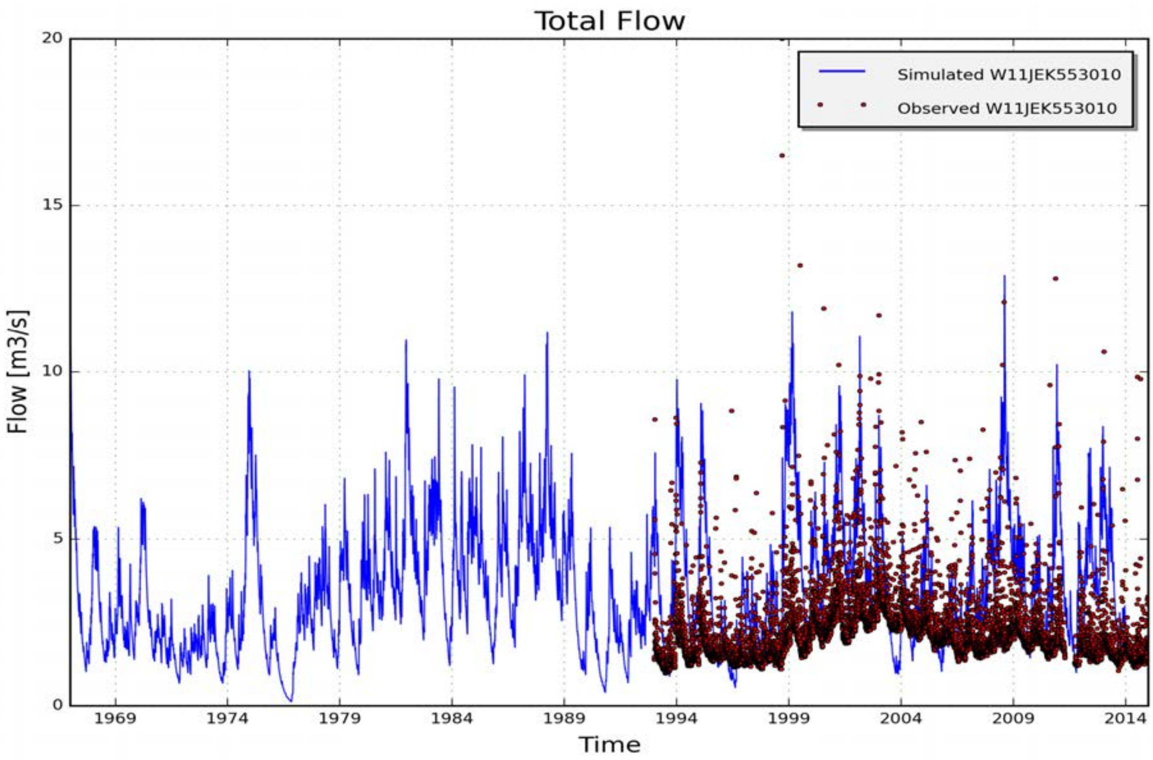


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11JEK553010, station unkown(calibration period)

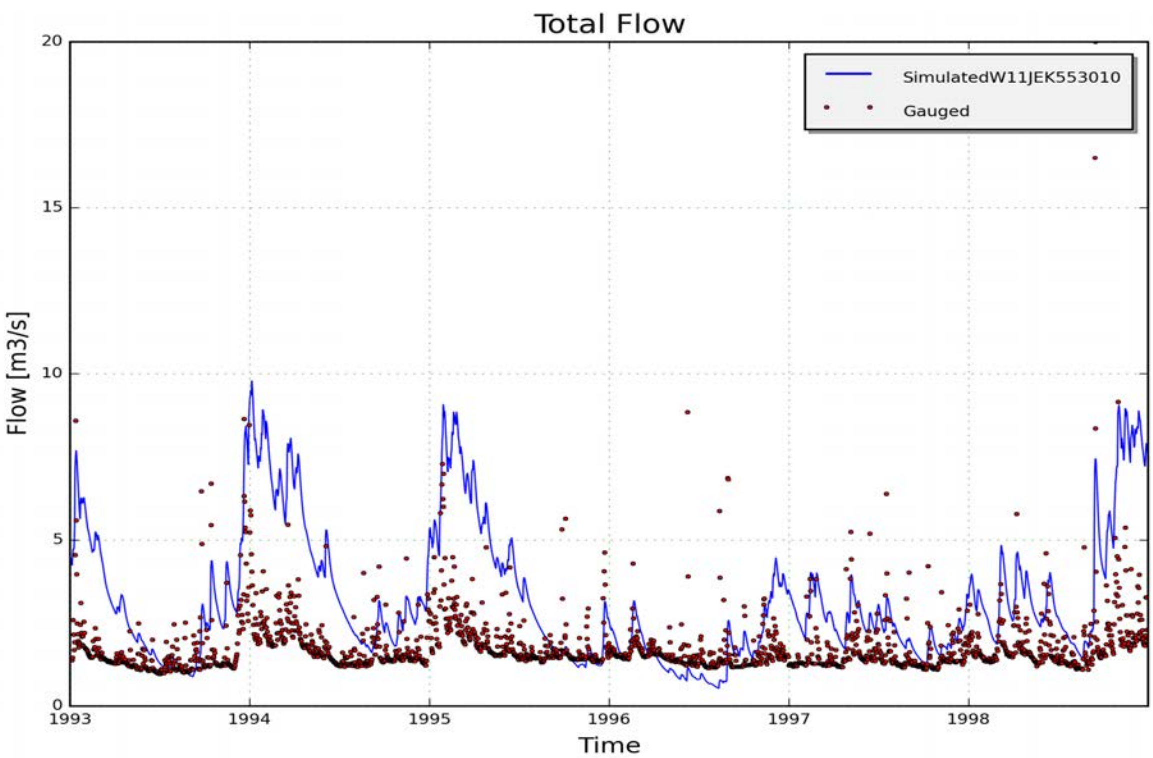
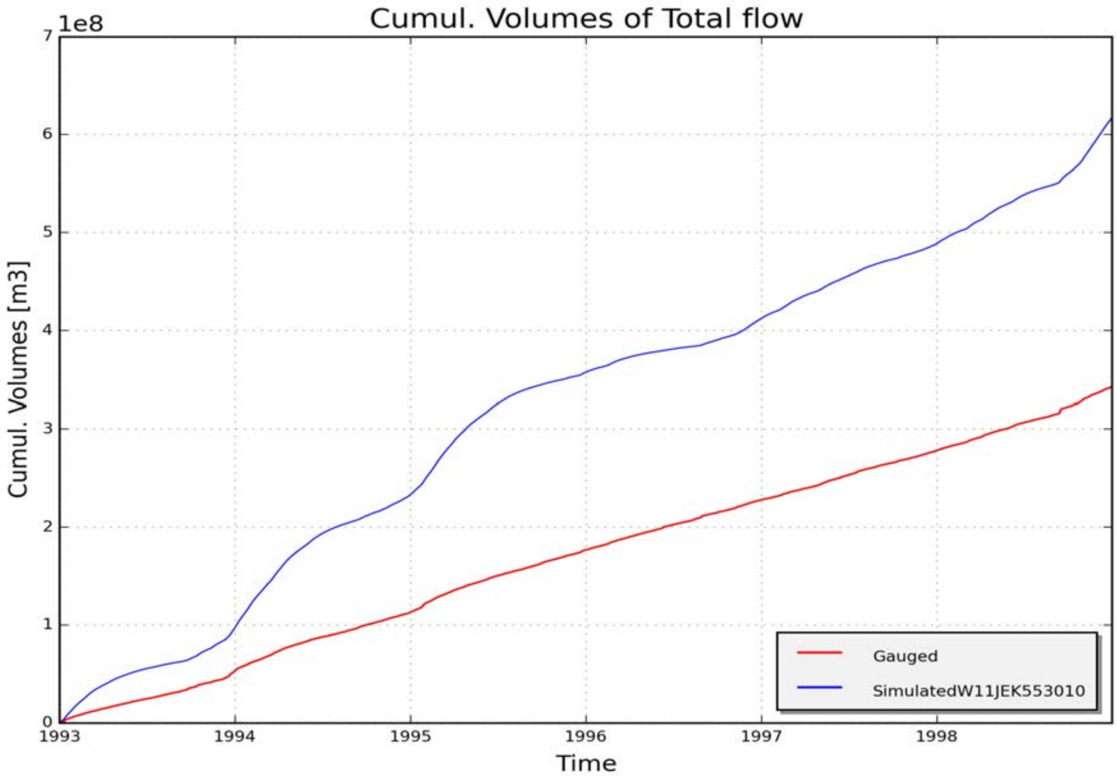


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11JEK553010, station unkown (calibration period)



Calibration and validation of NAM parameters for catchment "W11LES6610" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11LES6610 (Meuse)

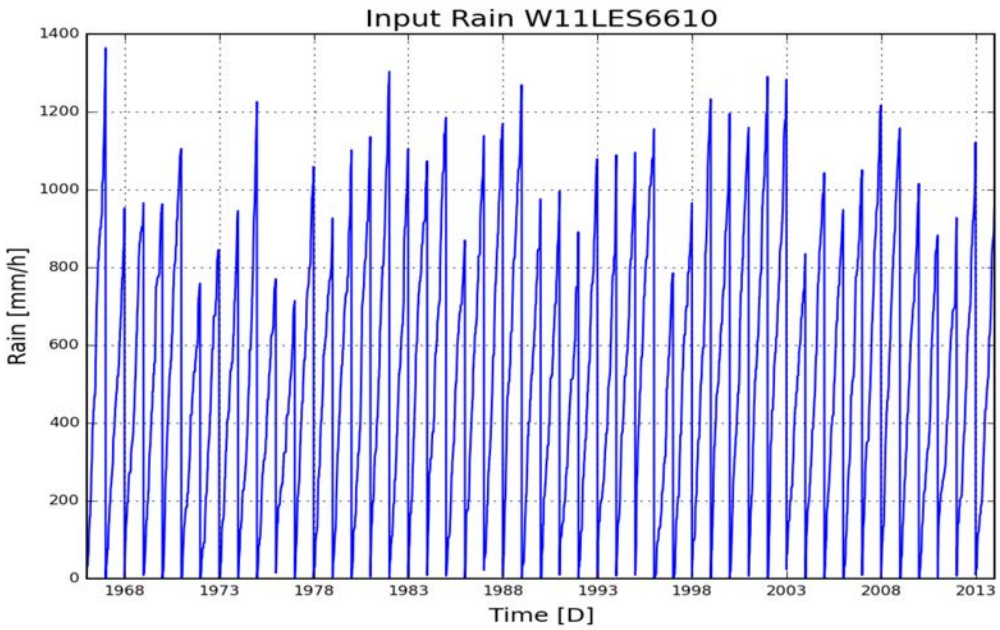
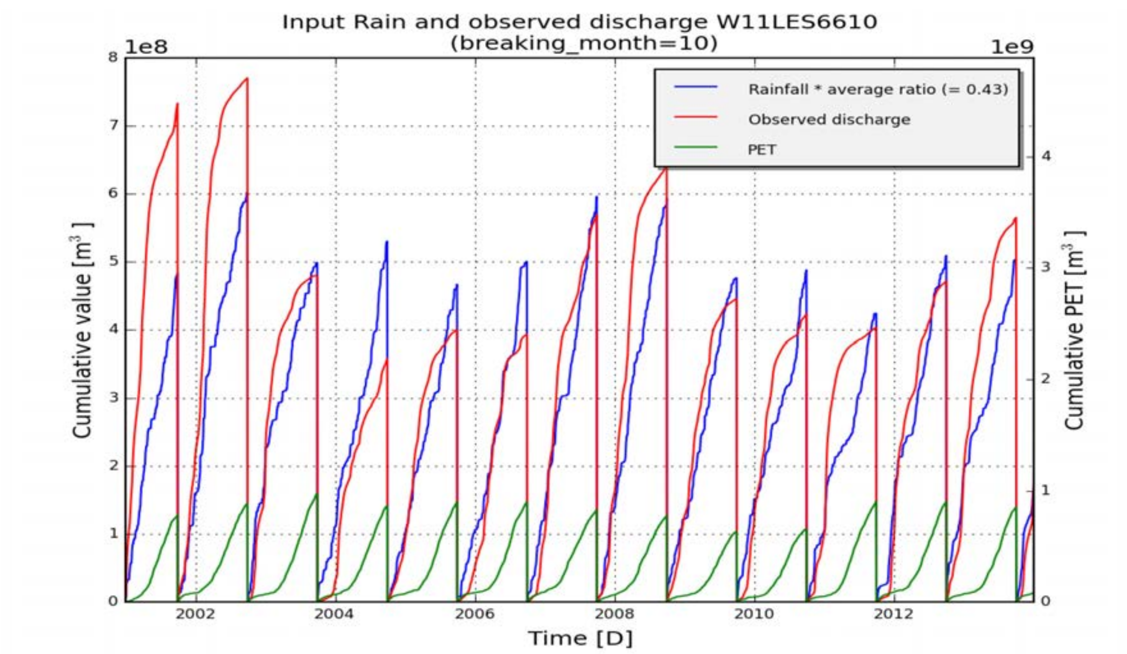


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11LES6610 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11LES6610
subcatchment_area [m^2]	1159000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	9.3 %	36.6 %	-0.9 %
NS	0.709	0.216	0.609
NS_log	0.652	0.049	0.657
NS_rel	0.067	-0.562	0.659
KGE	0.677	0.403	0.532

Goodness of fit for validation period (all available period 2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	9.3 %	36.6 %	-0.9 %
NS	0.709	0.216	0.609
NS_log	0.652	0.049	0.657
NS_rel	0.067	-0.562	0.659
KGE	0.677	0.403	0.532

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11LES6610, station Lesse, Herock (complete simulation period 1967-2013)

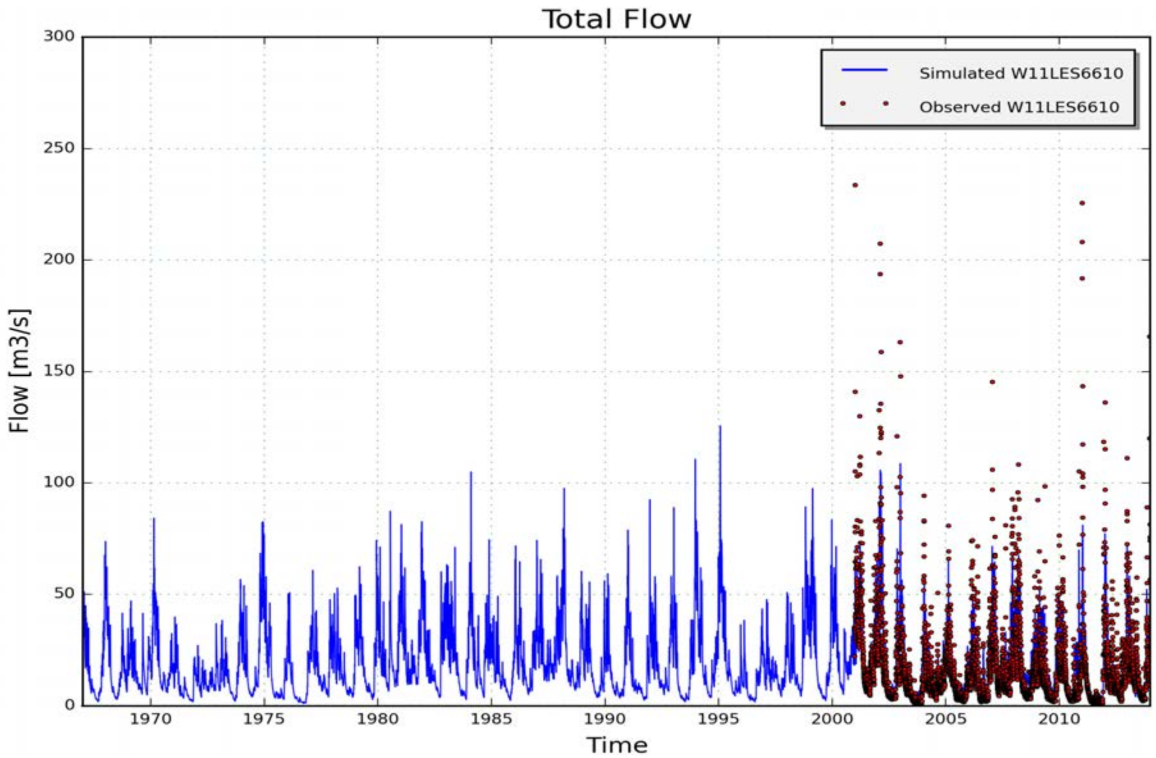


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11LES6610, station Lesse, Herock(calibration period)

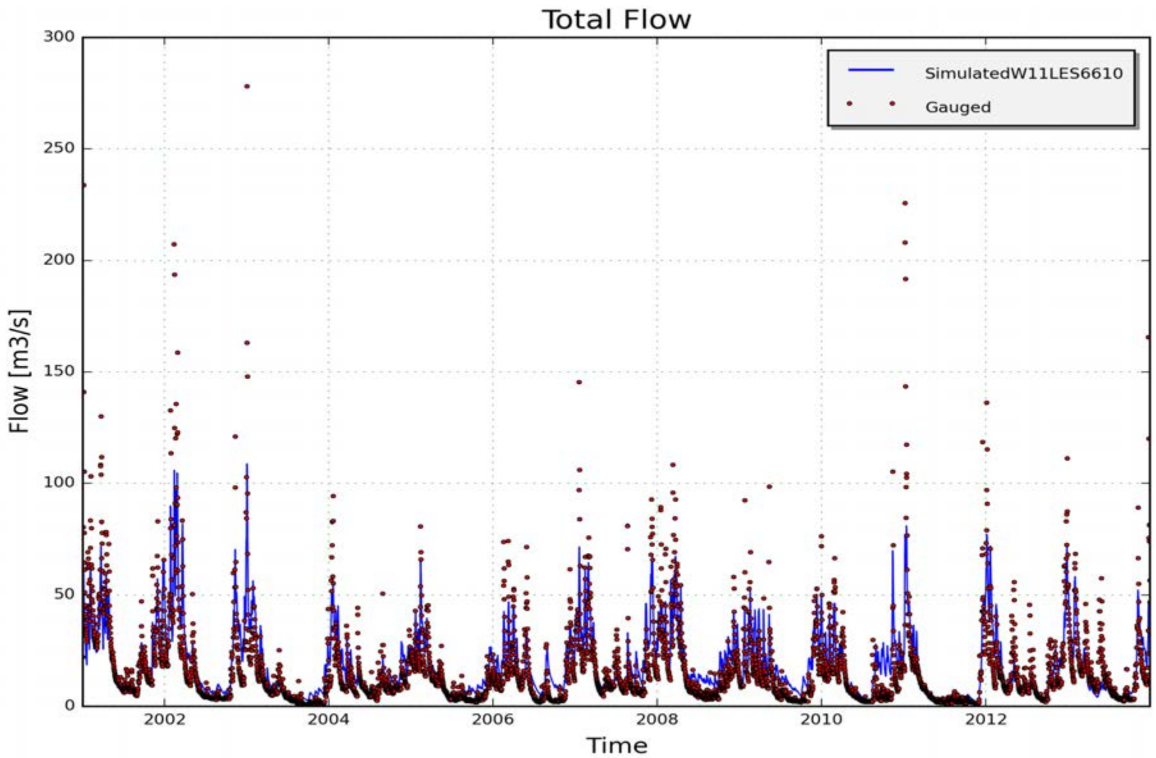


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11LES6610, station Lesse, Herock (calibration period)

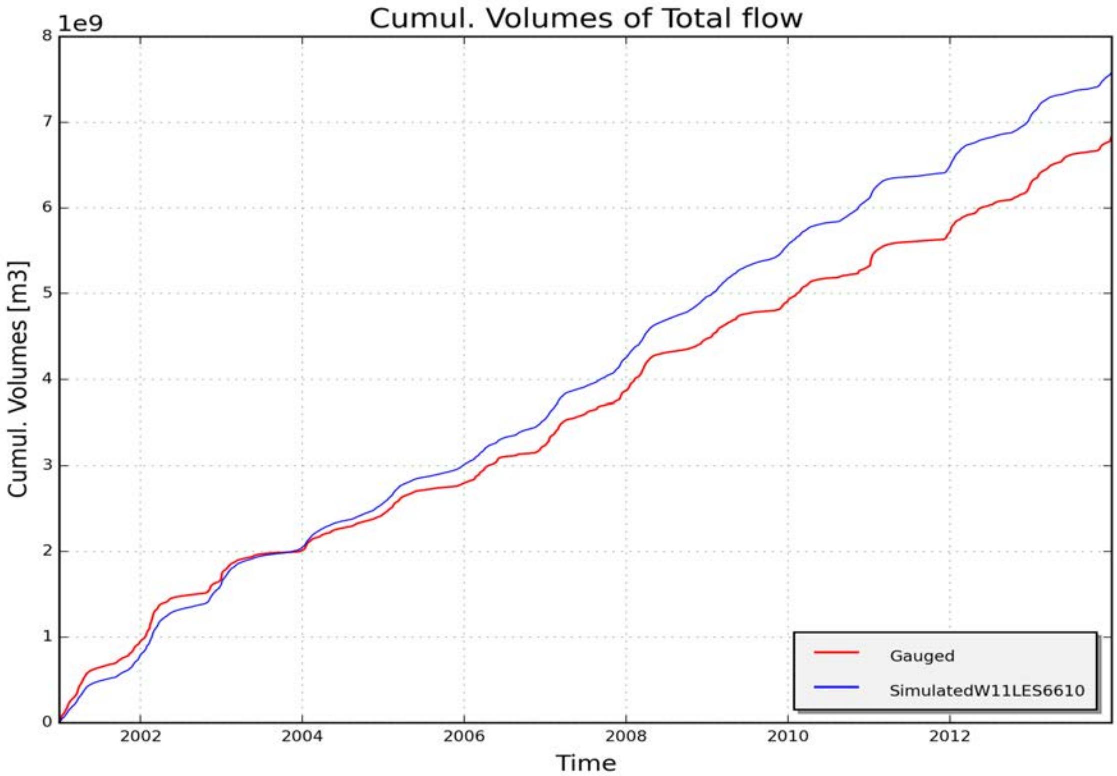
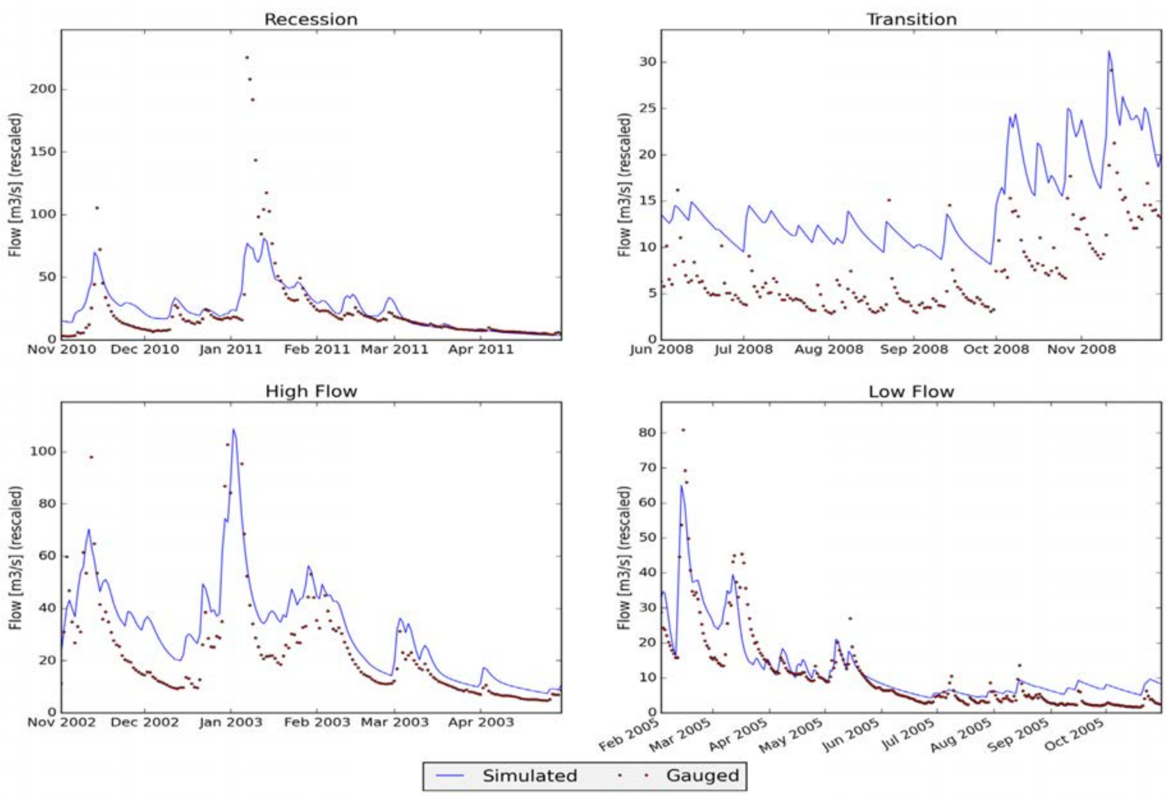


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11LES6610, station Lesse, Herock



Calibration and validation of NAM parameters for catchment "W11BOC8134" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11BOC8134 (Meuse)

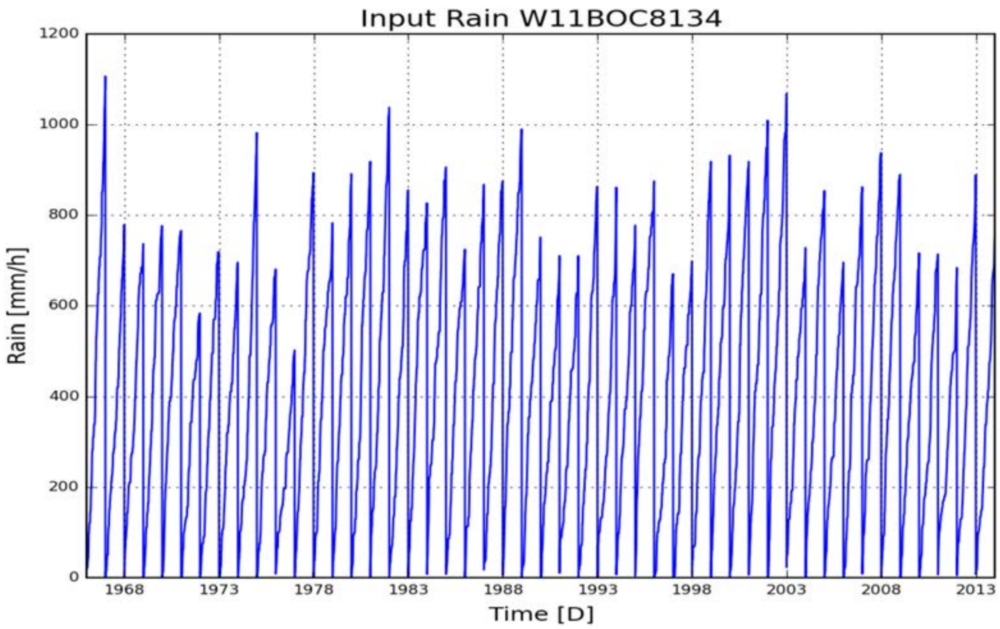
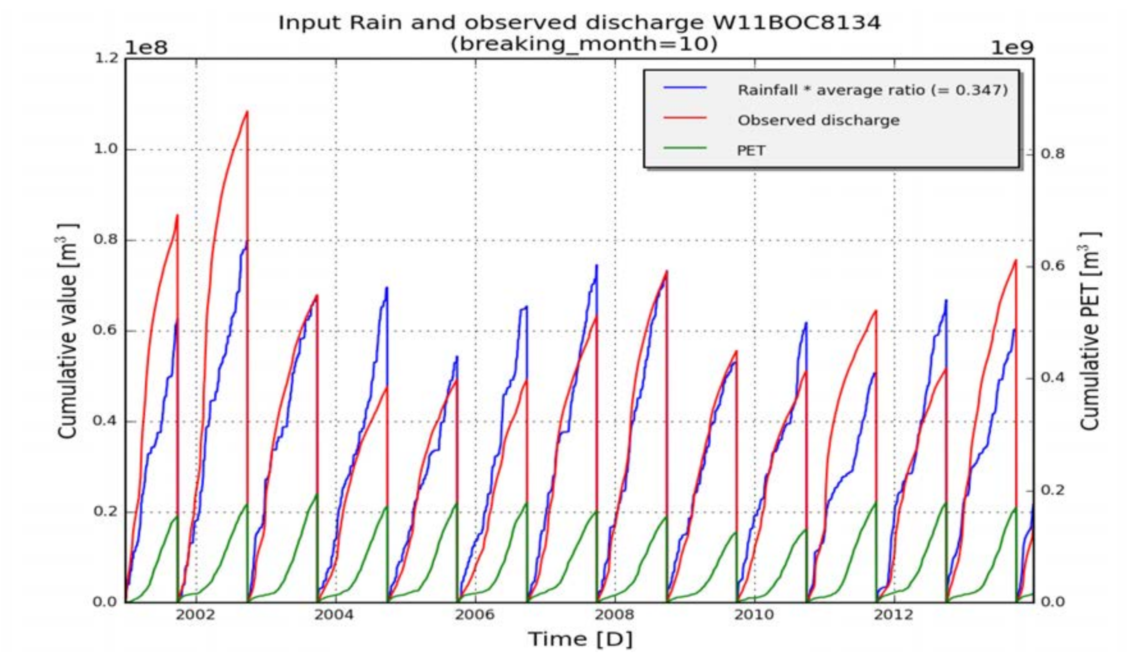


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11BOC8134 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11BOC8134
subcatchment_area [m^2]	230000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	15.1 %	-12.5 %	31.1 %
NS	0.548	-0.891	0.464
NS_log	-0.225	-5.765	0.297
NS_rel	0.643	-0.724	0.455
KGE	0.754	0.301	0.527

Goodness of fit for validation period (all available period 1979 - 2013)

	Full year	**Summer**	**Winter**
RelErr	8.3 %	-14.2 %	26.0 %
NS	0.555	0.3	0.5
NS_log	0.087	-2.284	0.391
NS_rel	0.658	0.742	0.387
KGE	0.77	0.437	0.605

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BOC8134, station Bocq, Yvoir (complete simulation period 1967-2013)

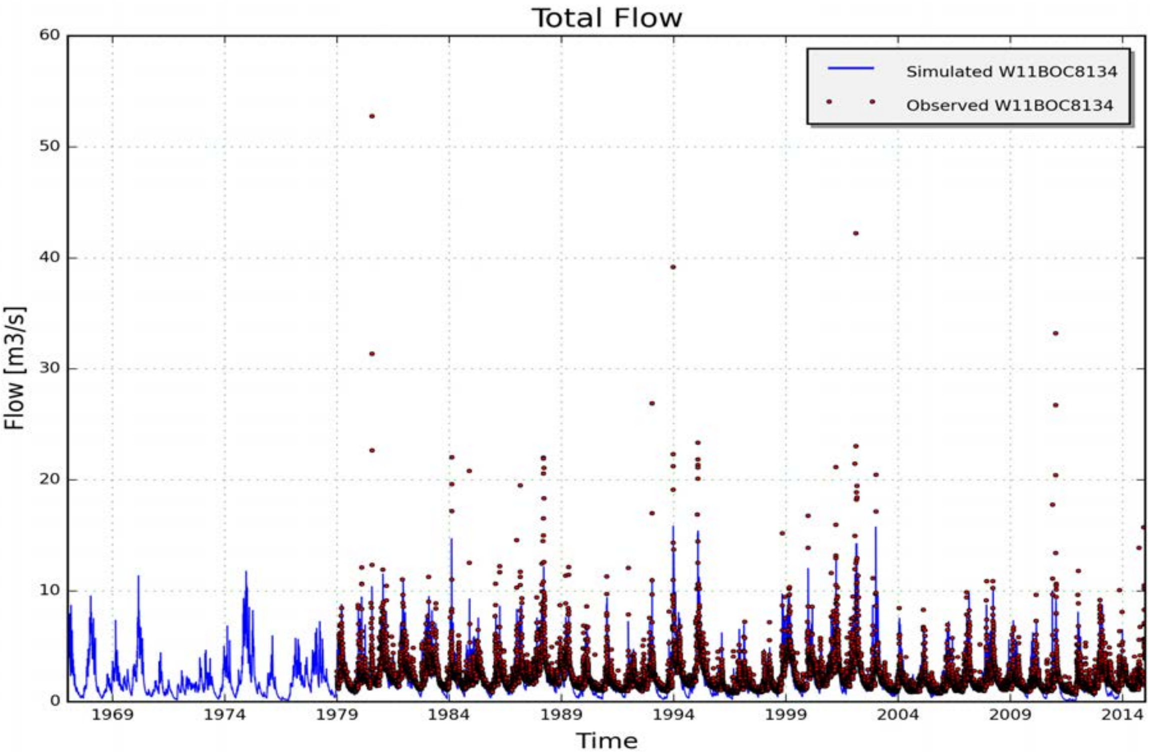


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BOC8134, station Bocq, Yvoir(calibration period)

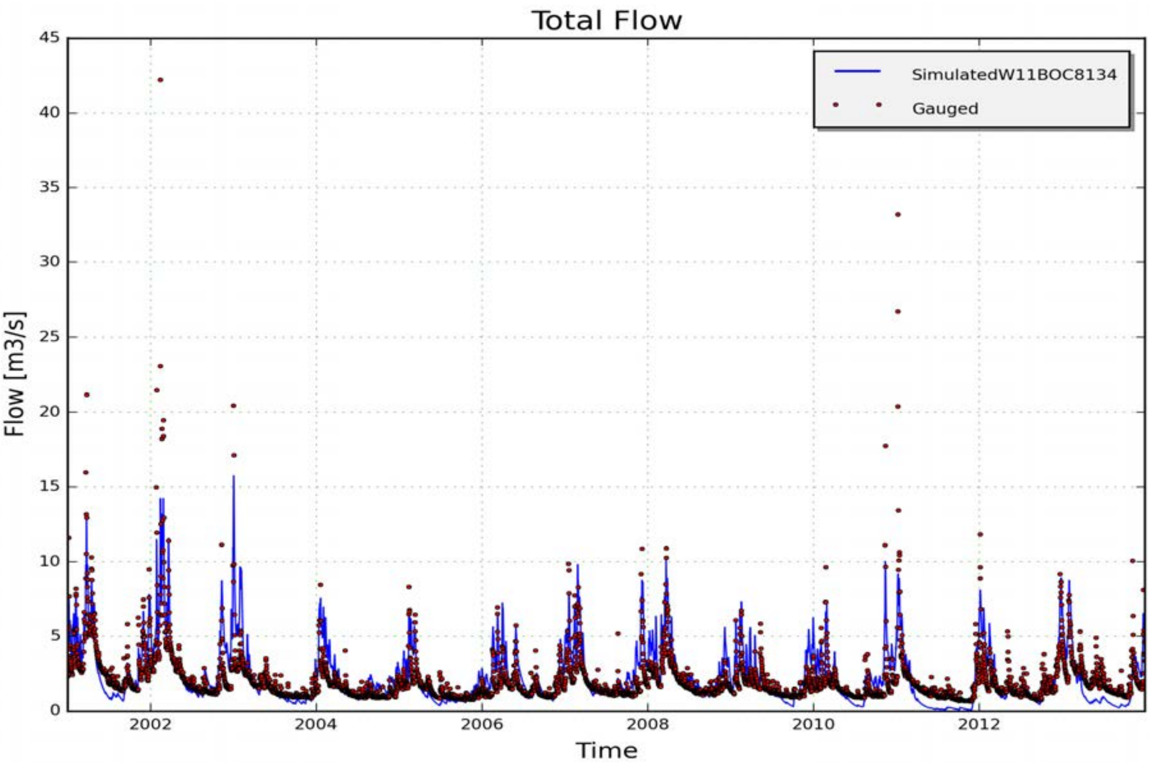


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11BOC8134, station Bocq, Yvoir (calibration period)

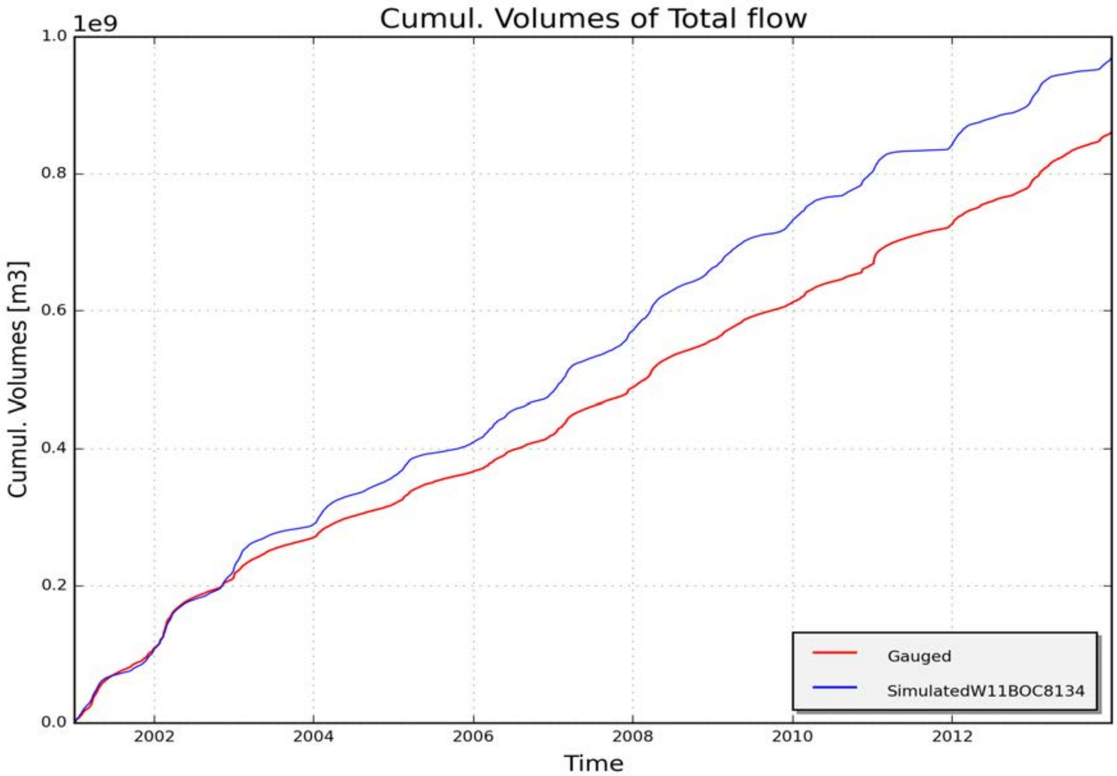
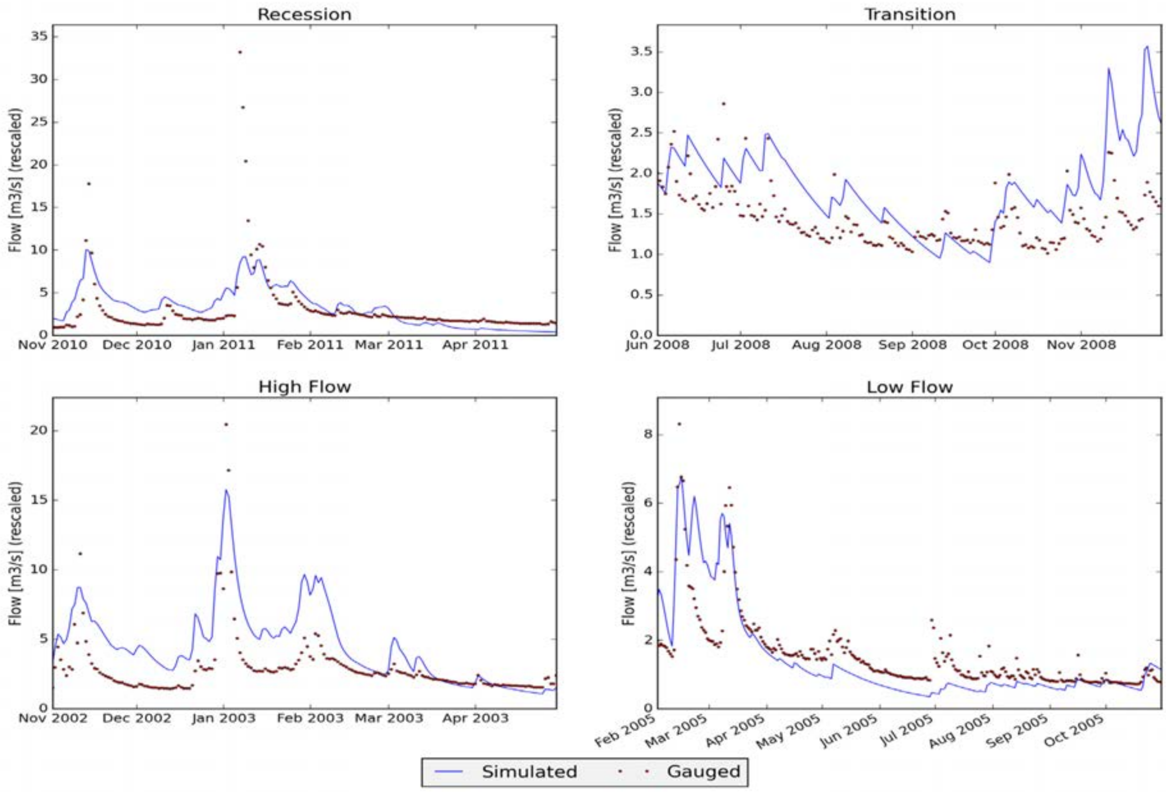


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11BOC8134, station Bocq, Yvoir



Calibration and validation of NAM parameters for catchment "W11MOL8163" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11MOL8163 (Meuse)

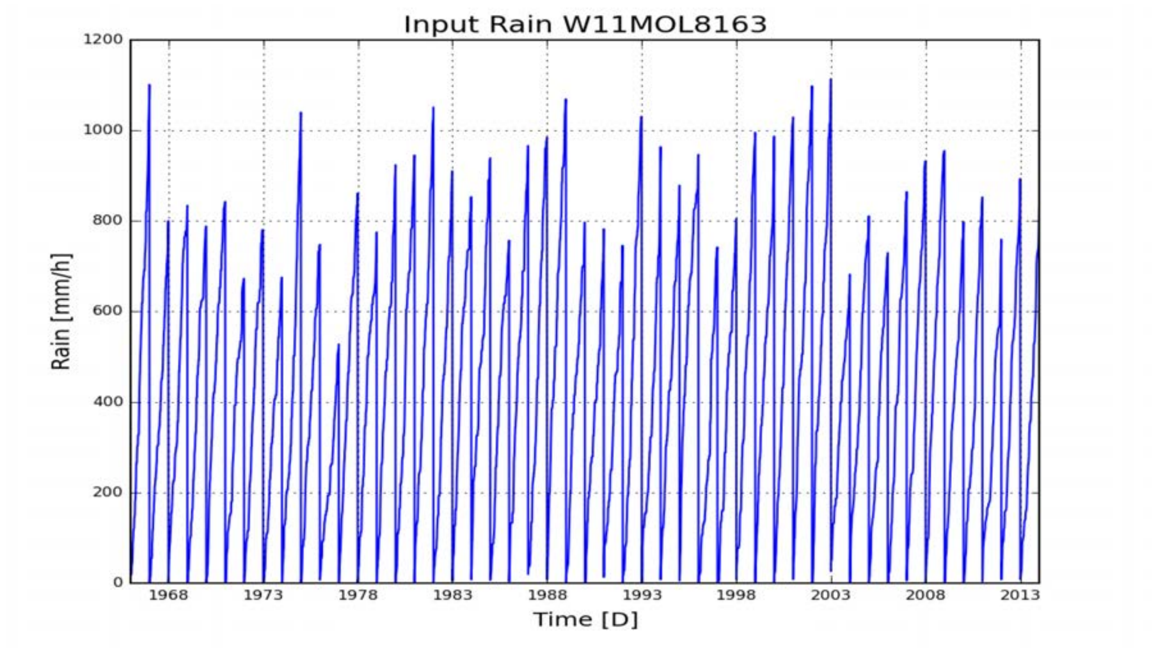
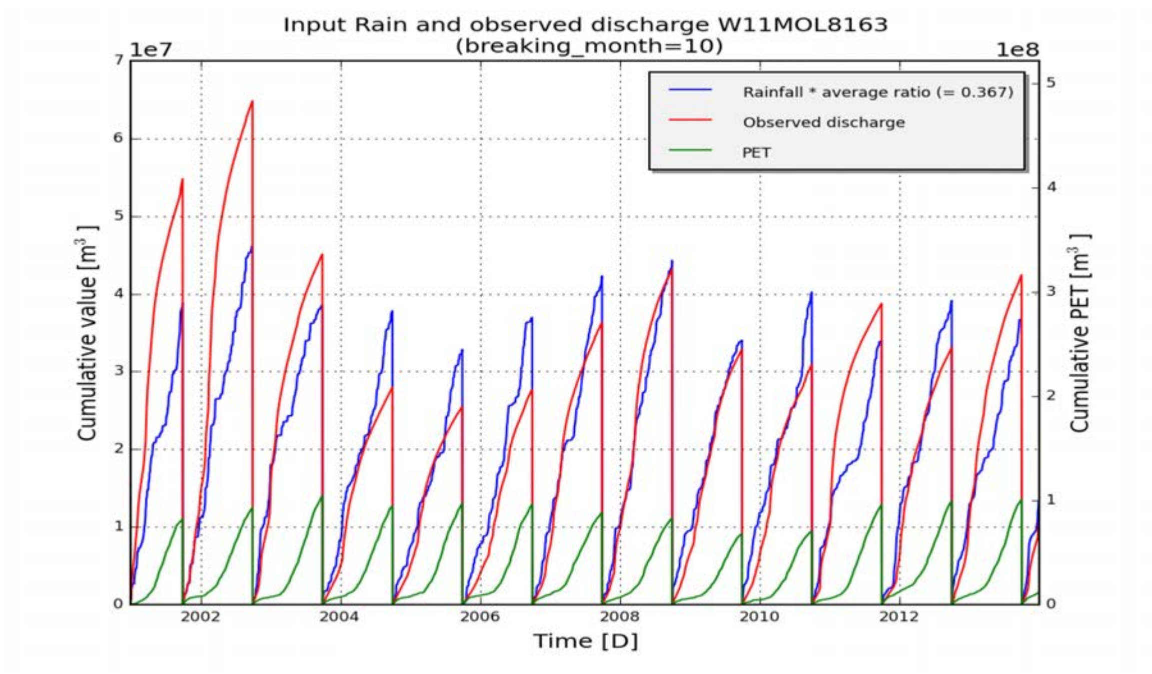


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11MOL8163 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11MOL8163
subcatchment_area [m²]	124000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	7.3 %	-22.9 %	21.0 %
NS	0.594	-1.478	0.559
NS_log	-0.024	-5.832	0.477
NS_rel	0.587	-1.525	0.49
KGE	0.794	0.216	0.623

Goodness of fit for validation period (all available period 1969 - 2013)

	Full year	**Summer**	**Winter**
RelErr	6.9 %	-17.9 %	24.2 %
NS	0.595	0.26	0.574
NS_log	0.108	-2.84	0.478
NS_rel	0.567	0.479	0.372
KGE	0.784	0.584	0.683

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MOL8163, station Molignee, Warnant (complete simulation period 1967-2013)

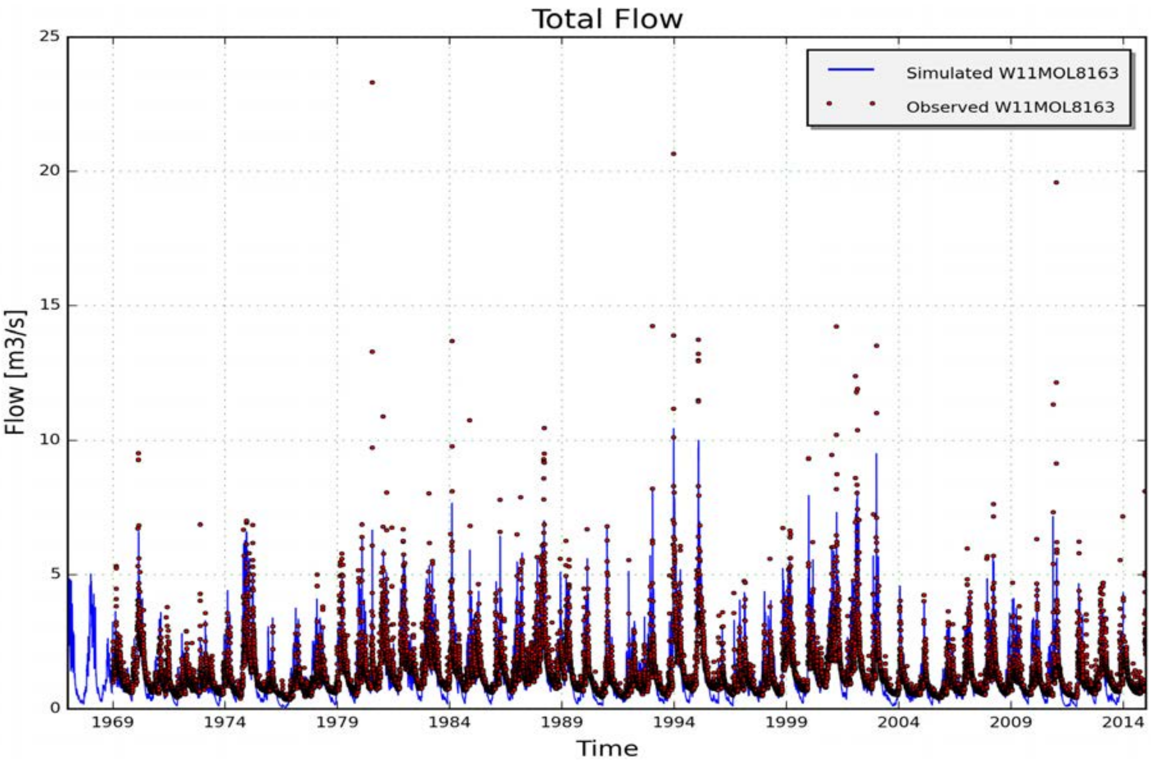


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11MOL8163, station Molignee, Warnant(calibration period)

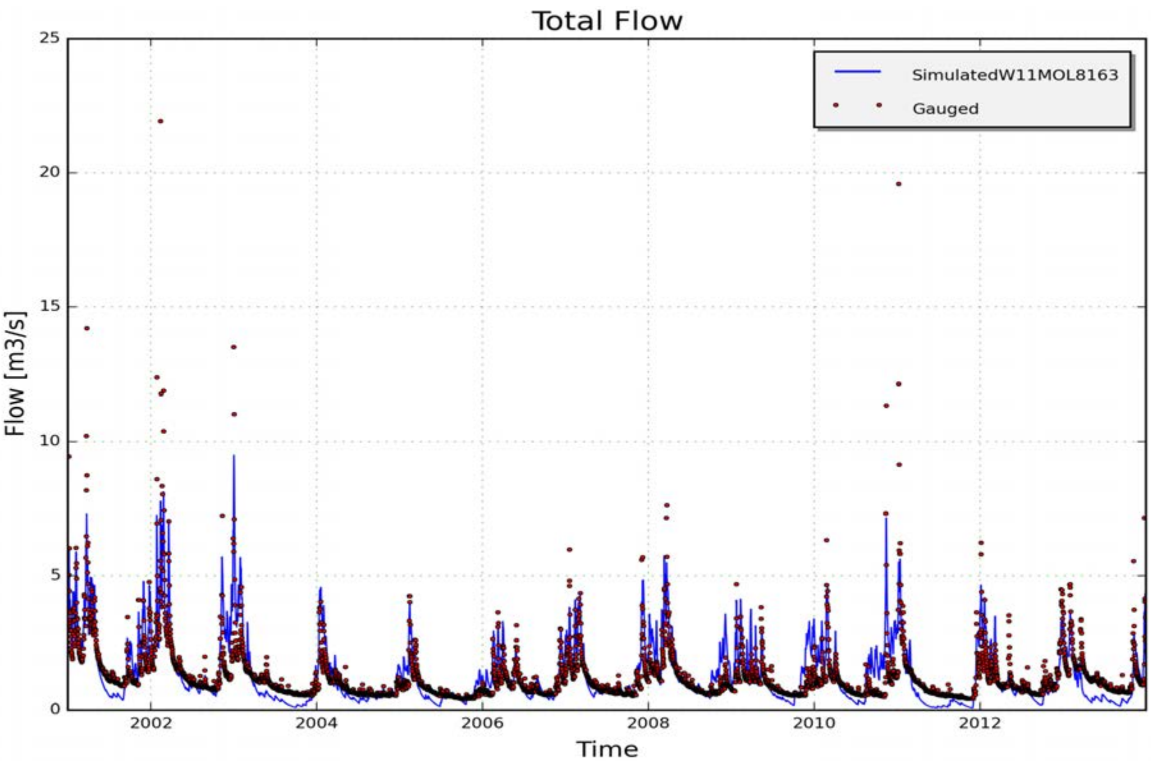


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11MOL8163, station Molignee, Warnant (calibration period)

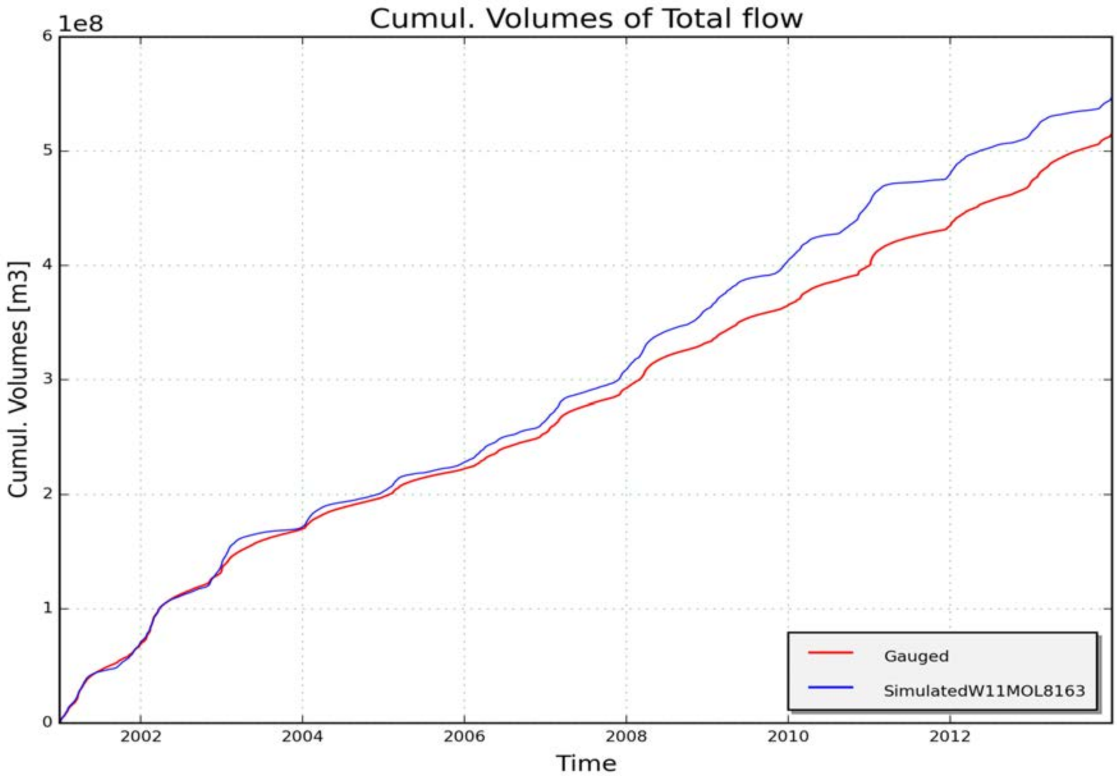
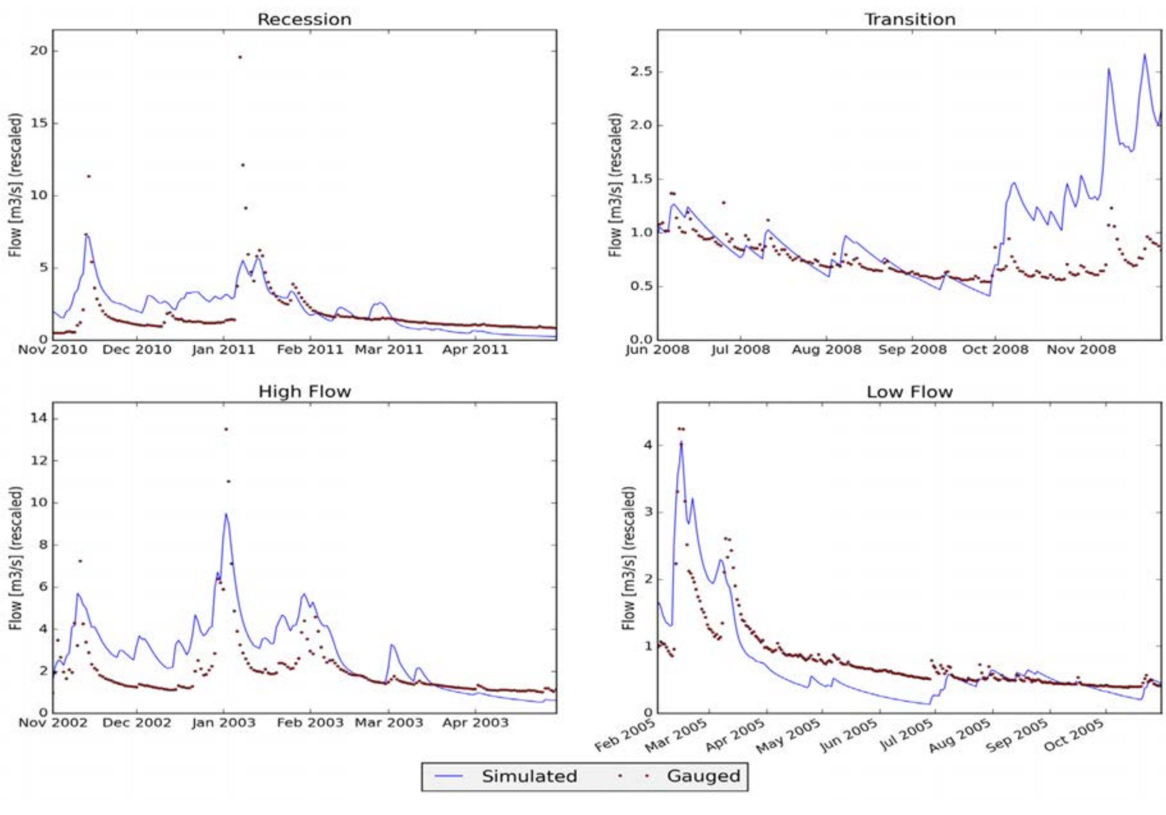


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11MOL8163, station Molignee, Warnant



Calibration and validation of NAM parameters for catchment "W11HER8622" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11HER8622 (Meuse)

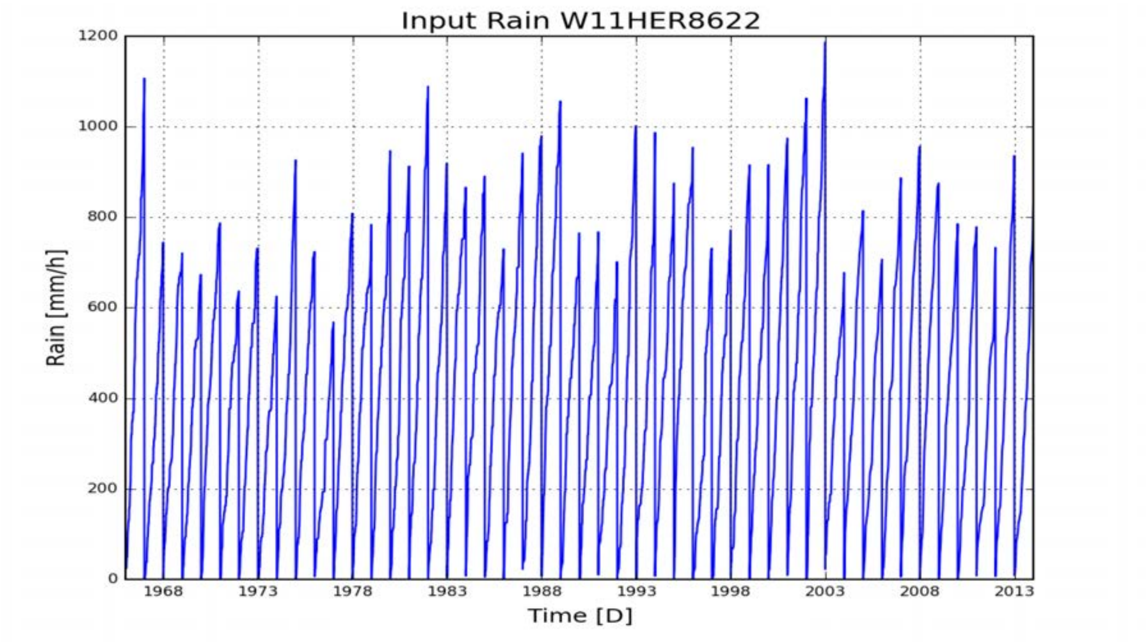
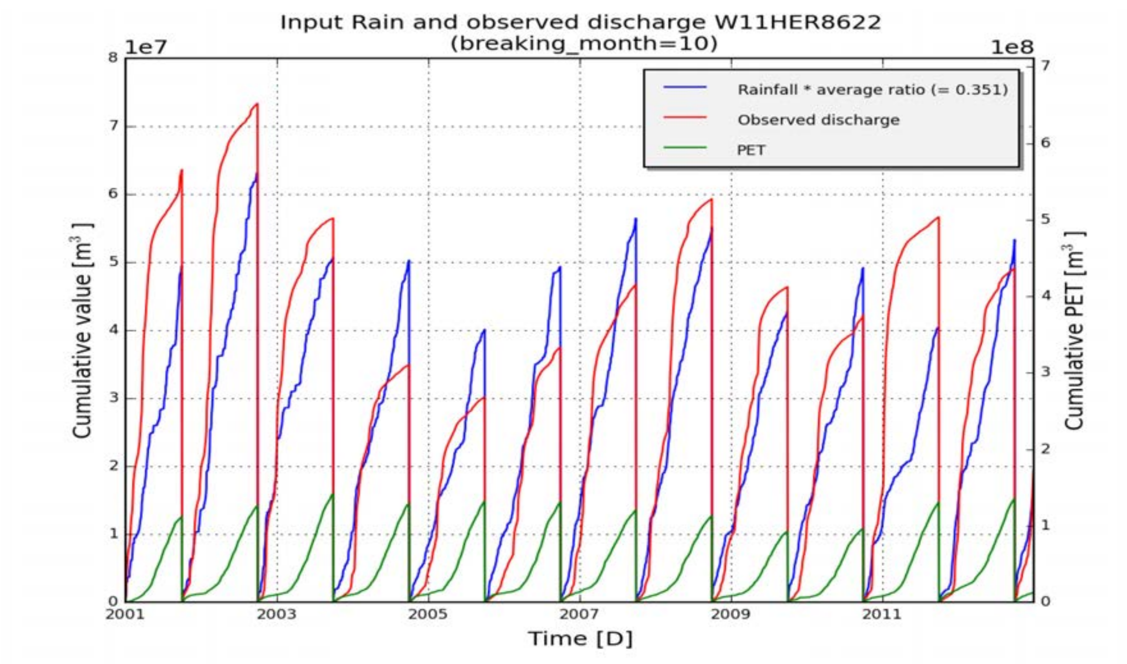


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11HER8622 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11HER8622
subcatchment_area [m^2]	169000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 3.77), ('SMmax.C', 132.0), ('CQOF.C', 0.32), ('CKBF.C', 948.0), ('CKIF.C', 74.0), ('CK1.C', 23.0), ('CK2.C', 51.0), ('TIF.C', 0.69), ('TOF.C', 0.56), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2012)

	Full year	**Summer**	**Winter**
RelErr	13.0 %	61.3 %	4.8 %
NS	0.555	-0.174	0.437
NS_log	0.638	-1.01	0.514
NS_rel	0.68	-0.186	0.556
KGE	0.545	0.329	0.389

Goodness of fit for validation period (all available period 1969 - 2012)

	Full year	**Summer**	**Winter**
RelErr	10.7 %	53.7 %	5.4 %
NS	0.595	0.265	0.521
NS_log	0.632	-0.381	0.57
NS_rel	0.477	0.589	0.463
KGE	0.579	0.154	0.486

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HER8622, station Hermeton, Hastieres (complete simulation period 1967-2013)

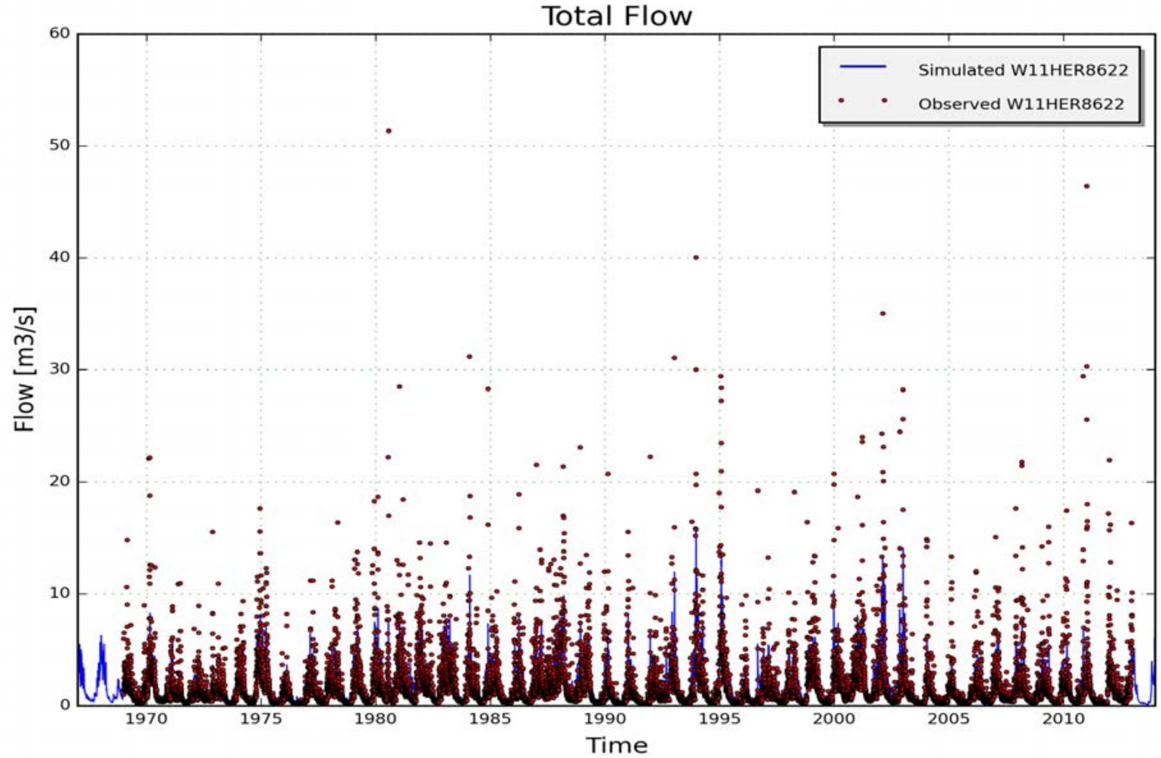


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HER8622, station Hermeton, Hastieres(calibration period)

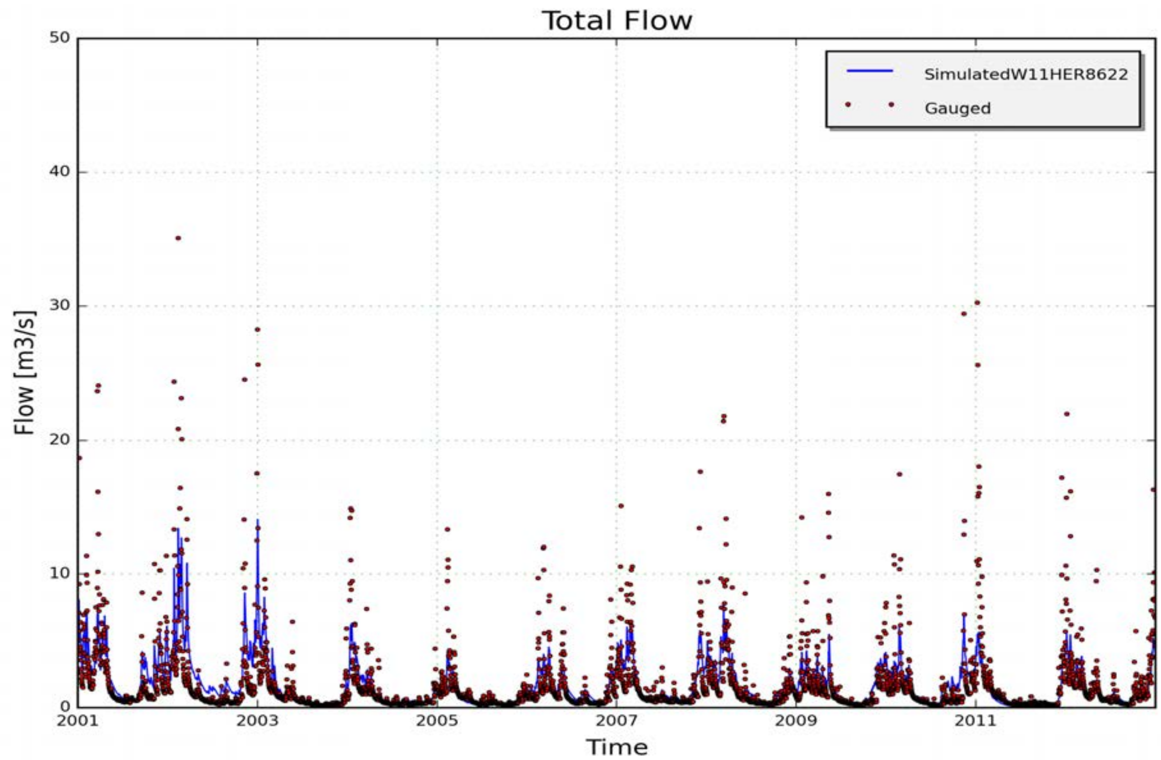


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11HER8622, station Hermeton, Hastieres (calibration period)

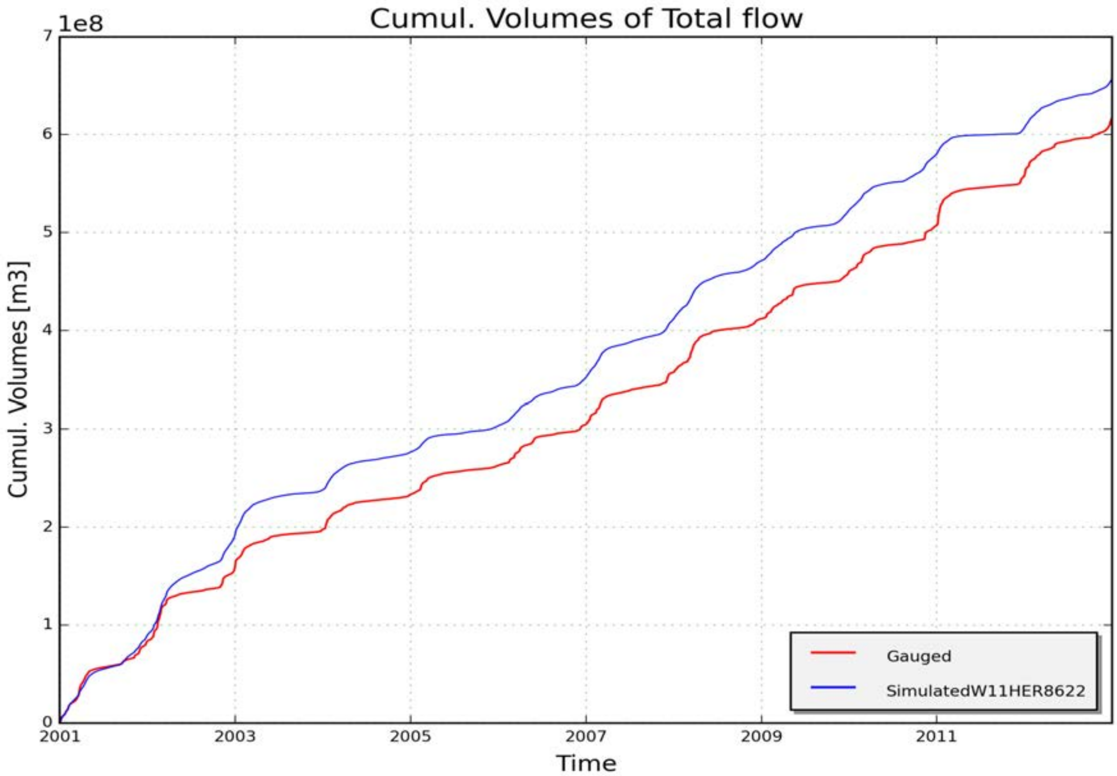
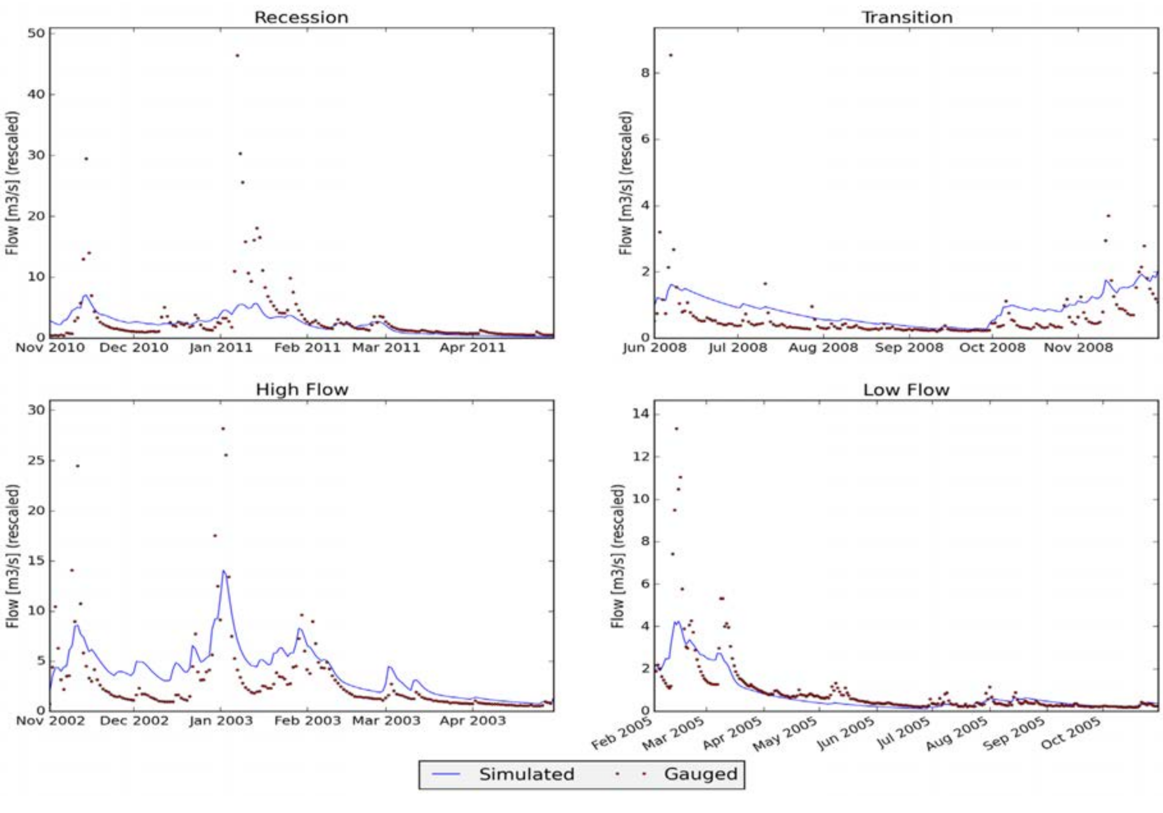


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11HER8622, station Hermeton, Hastieres



Calibration and validation of NAM parameters for catchment "W11BIE5442" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11BIE5442 (Meuse)

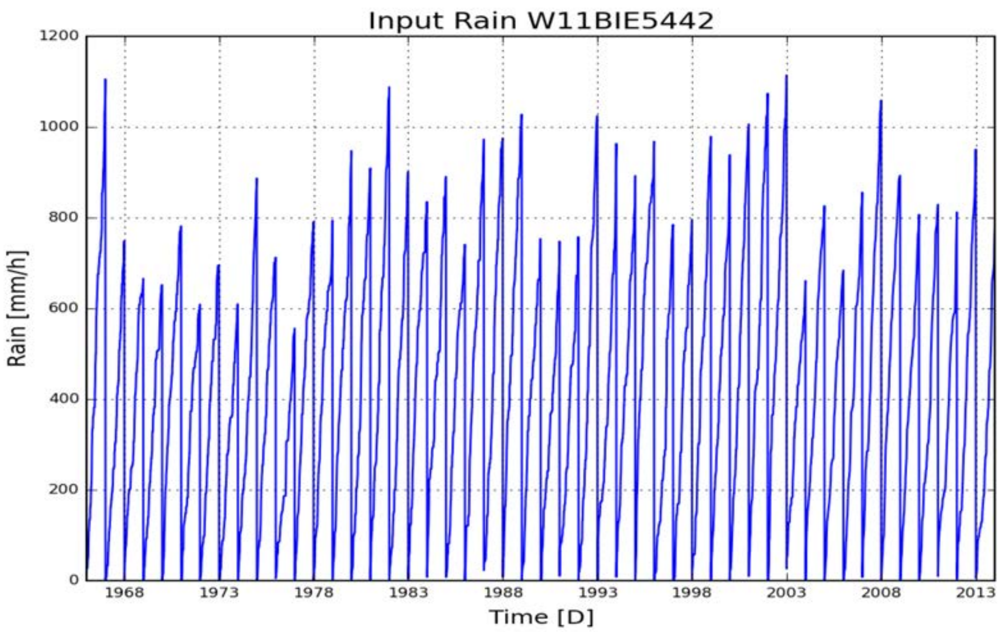
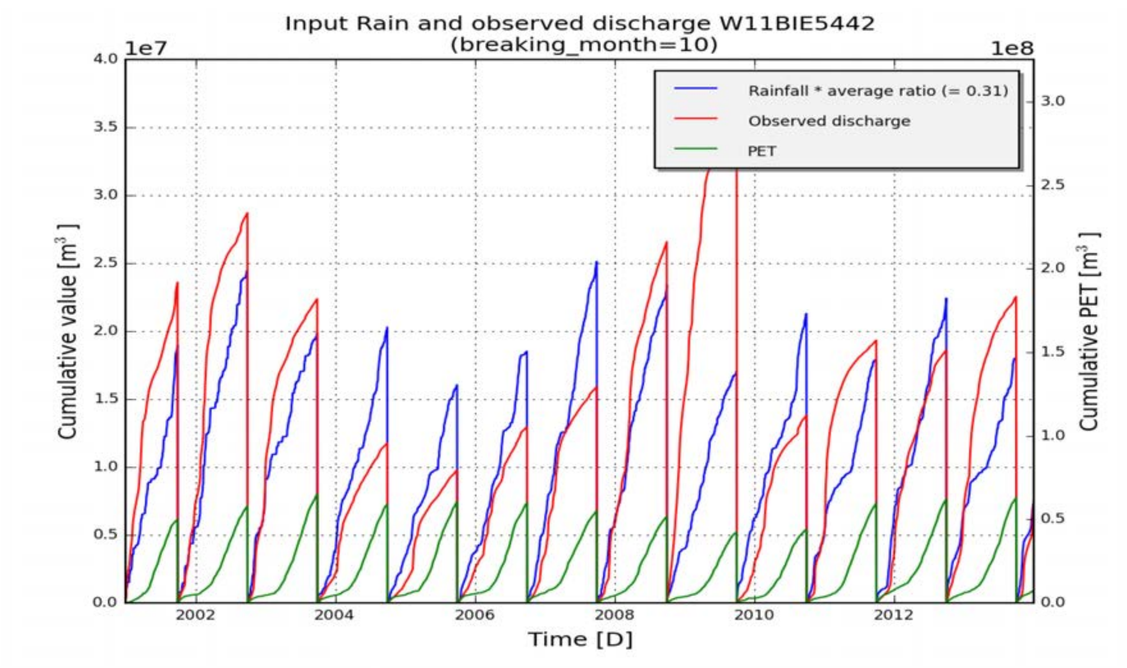


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11BIE5442 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11BIE5442
subcatchment_area [m^2]	77278800
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	19.6 %	35.8 %	10.2 %
NS	0.466	-0.251	0.439
NS_log	0.401	-0.278	0.403
NS_rel	0.216	-1.249	0.291
KGE	0.572	0.425	0.485

Goodness of fit for validation period (all available period 2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	19.3 %	35.6 %	9.8 %
NS	0.467	-0.246	0.44
NS_log	0.402	-0.277	0.403
NS_rel	0.217	-1.248	0.291
KGE	0.571	0.427	0.483

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BIE5442, station Biesme, Aiseau (complete simulation period 1967-2013)

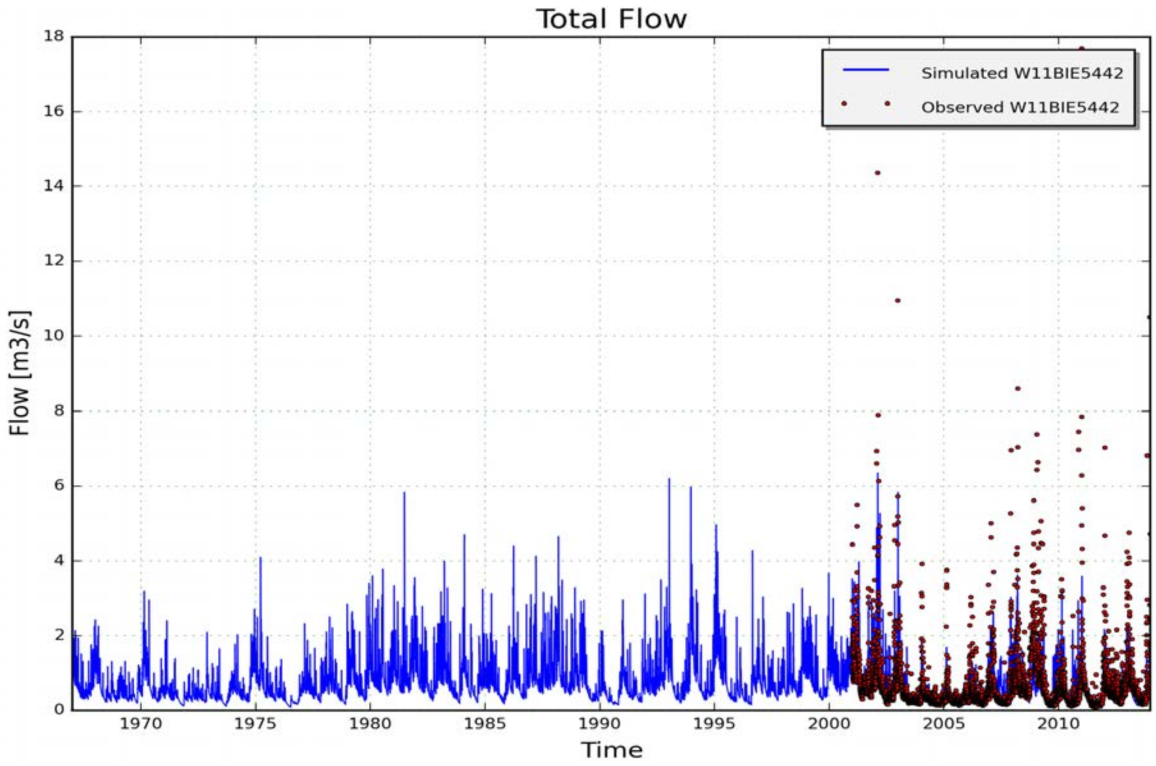


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BIE5442, station Biesme, Aiseau(calibration period)

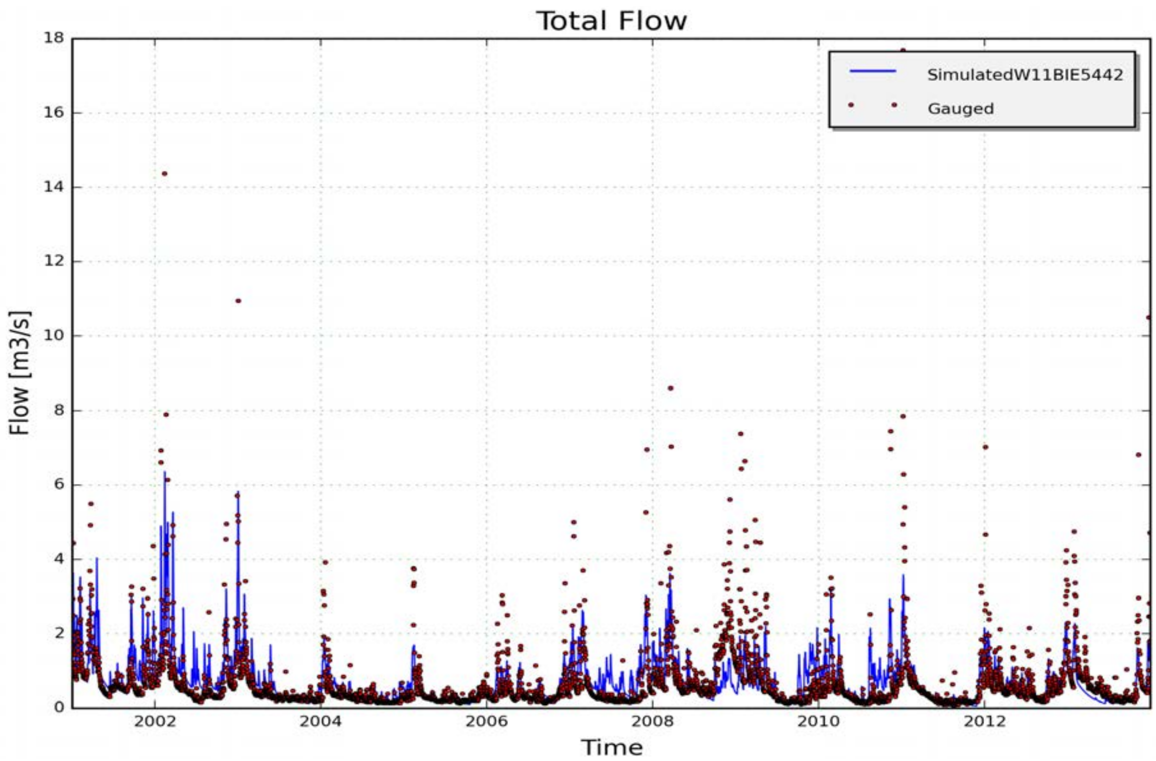


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11BIE5442, station Biesme, Aiseau (calibration period)

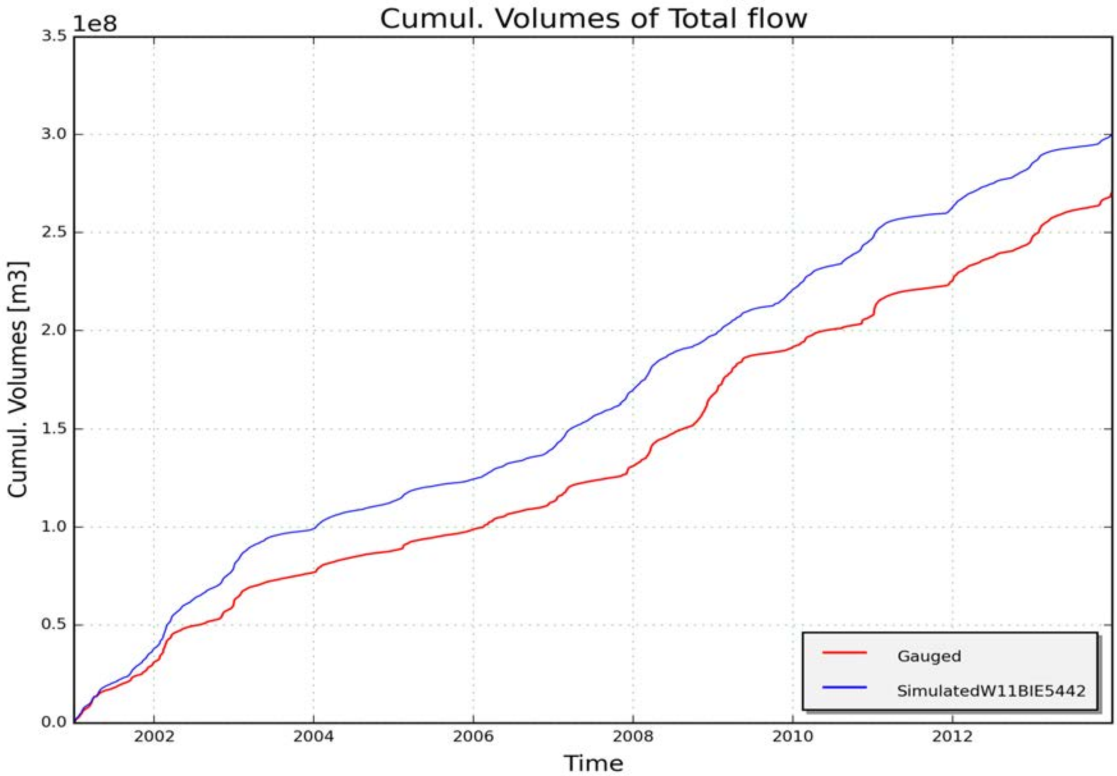
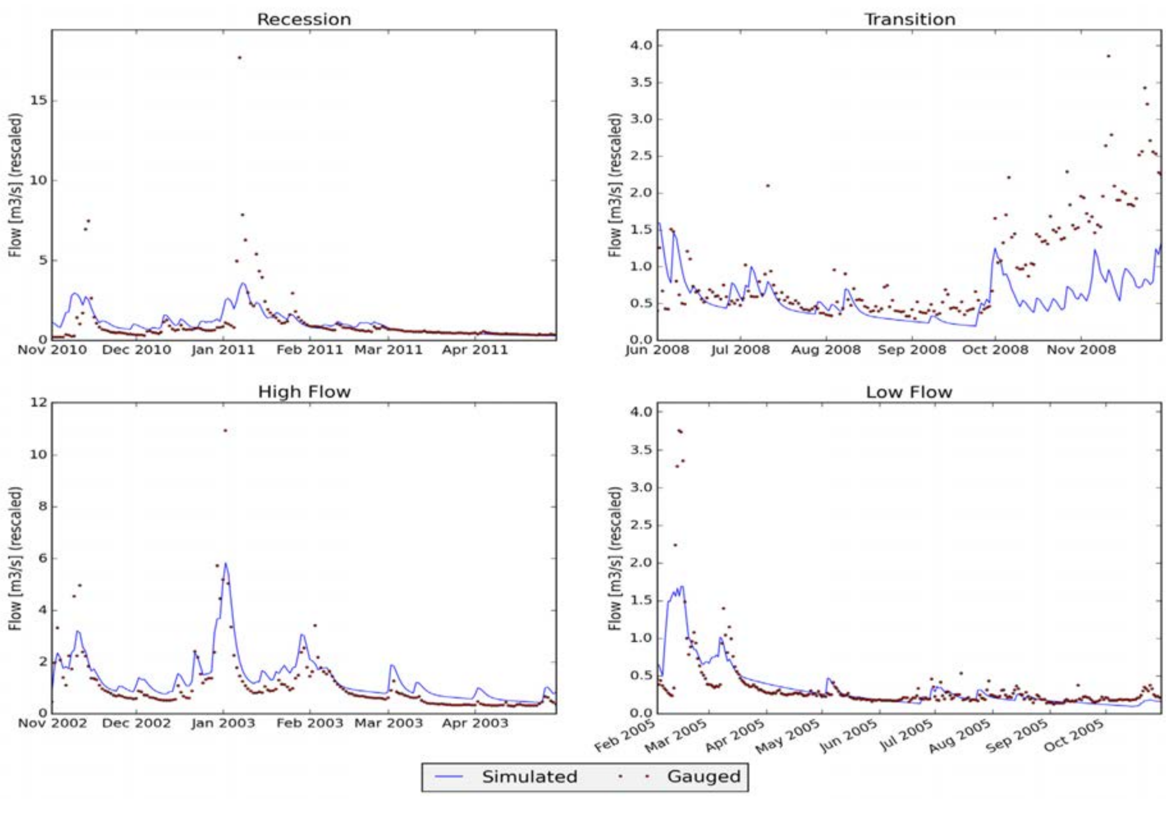


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11BIE5442, station Biesme, Aiseau



Calibration and validation of NAM parameters for catchment "W11BLE6630" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11BLE6630 (Meuse)

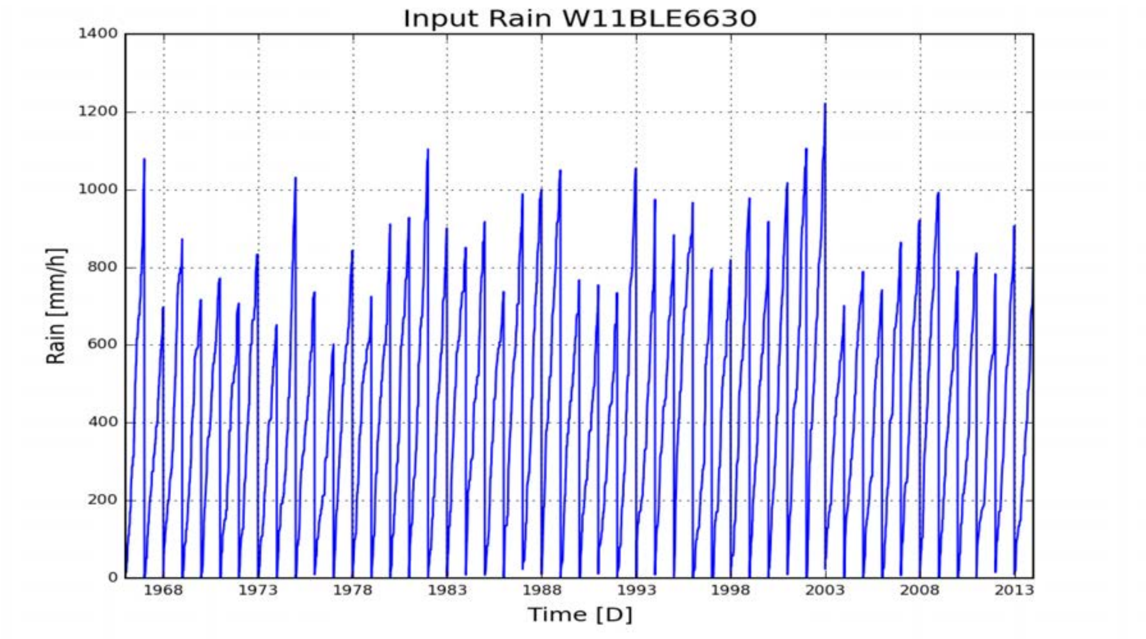
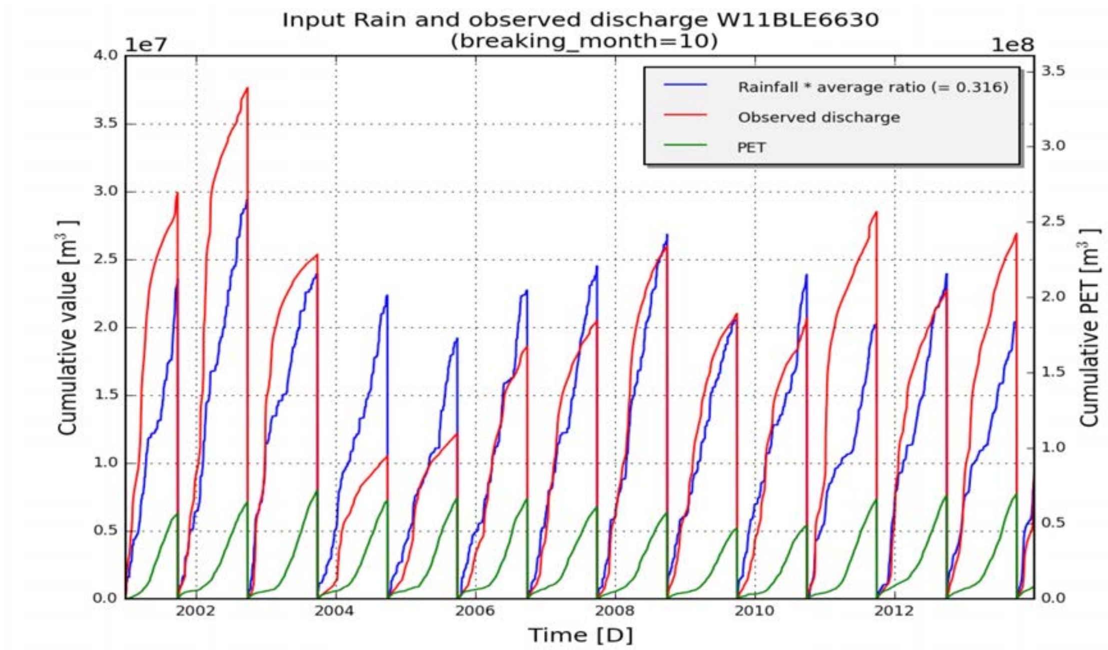


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11BLE6630 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11BLE6630
subcatchment_area [m^2]	85627700
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	29.7 %	111.9 %	3.3 %
NS	0.501	-0.821	0.465
NS_log	0.367	-2.045	0.648
NS_rel	0.583	-0.677	0.749
KGE	0.478	0.007	0.404

Goodness of fit for validation period (all available period 2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	29.4 %	111.6 %	3.0 %
NS	0.501	-0.814	0.465
NS_log	0.367	-2.041	0.648
NS_rel	0.584	-0.674	0.75
KGE	0.477	0.008	0.403

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BLE6630, station Biesme l'eau, Thuin (complete simulation period 1967-2013)

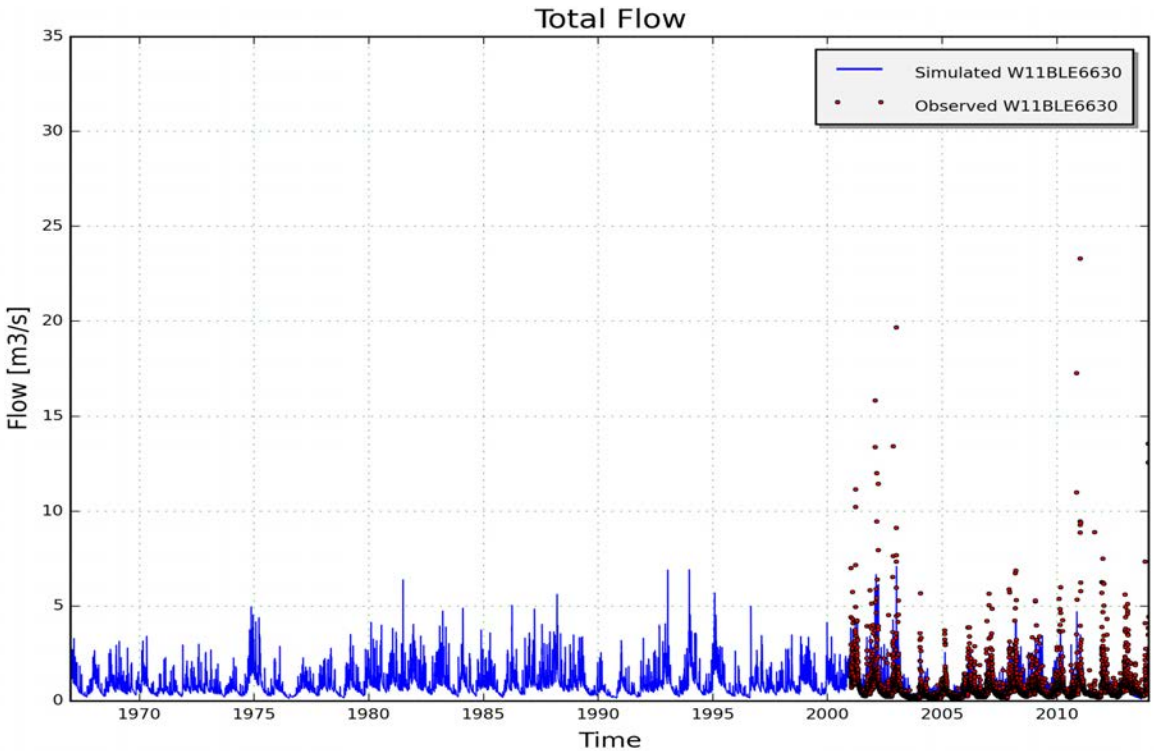


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11BLE6630, station Biesme l'eau, Thuin(calibration period)

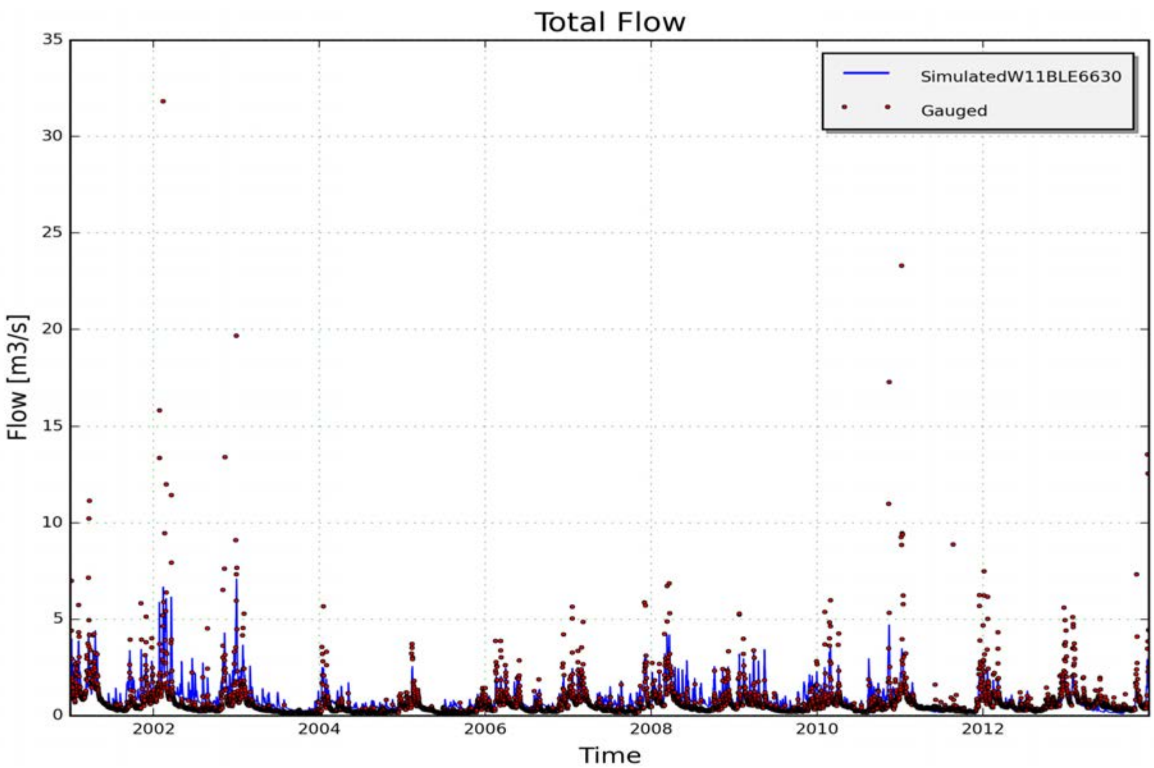


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11BLE6630, station Biesme l'eau, Thuin (calibration period)

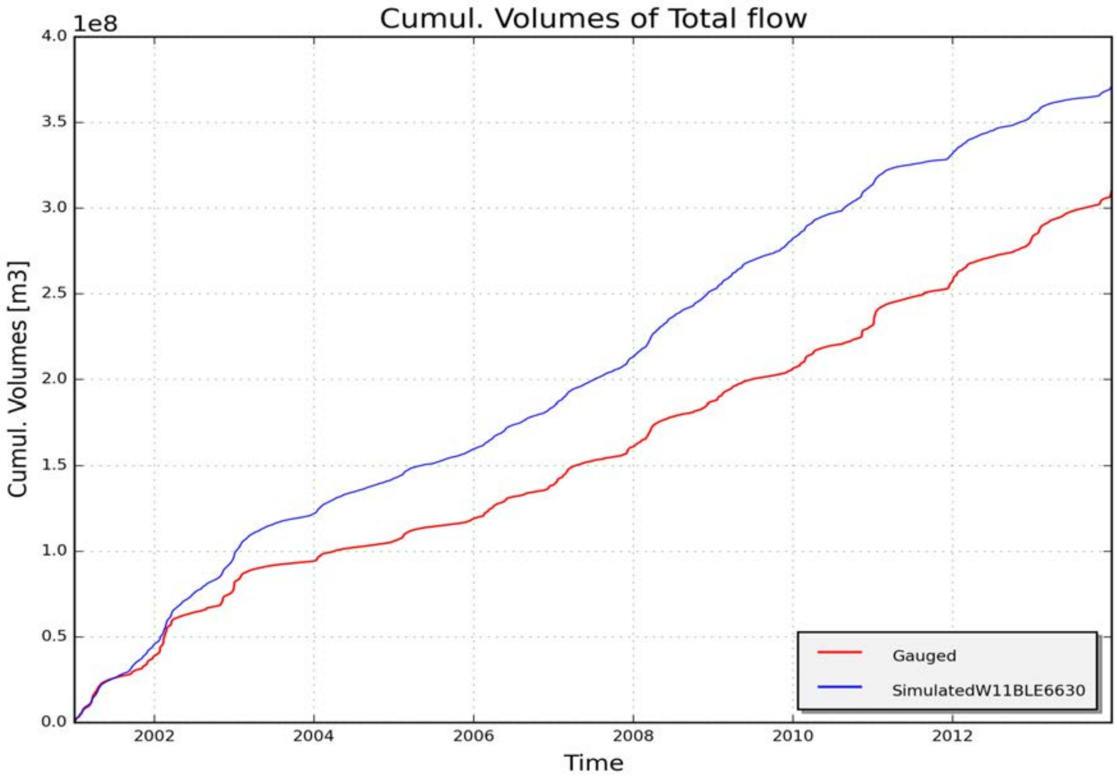
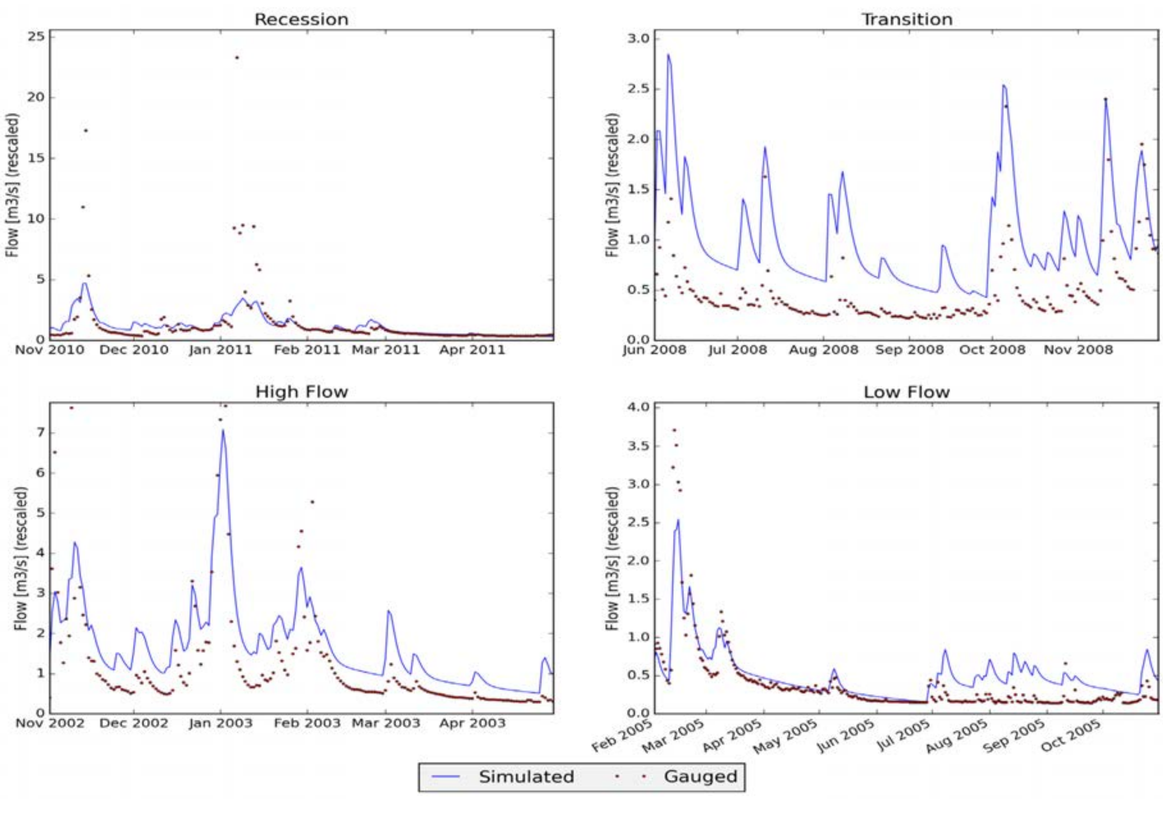


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11BLE6630, station Biesme l'eau, Thuin



Calibration and validation of NAM parameters for catchment "W11ORN7241" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11ORN7241 (Meuse)

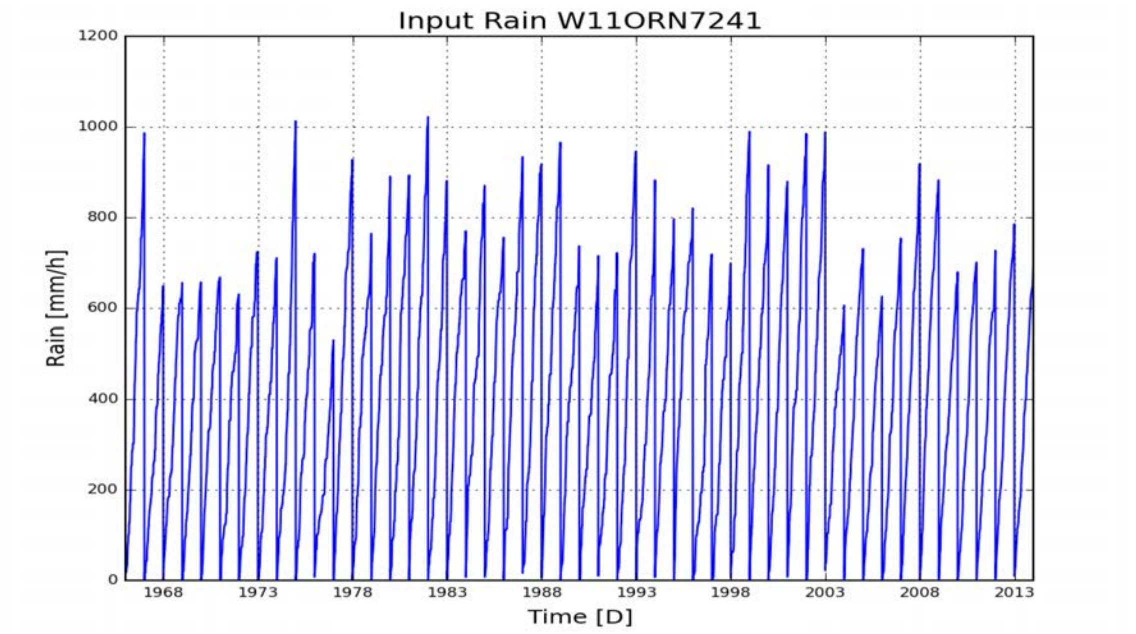
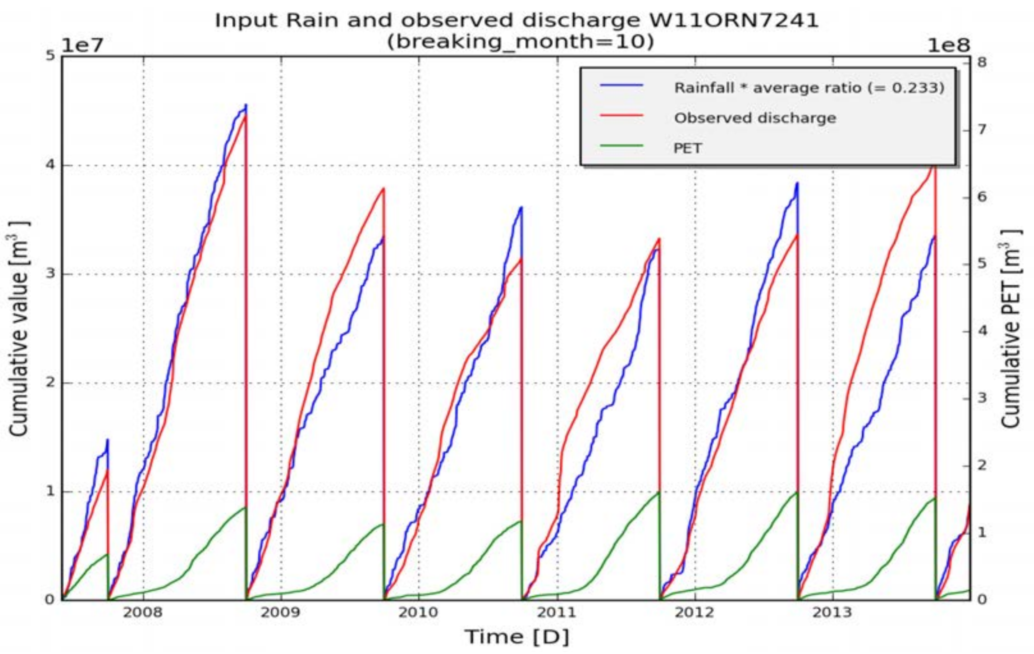


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11ORN7241 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11ORN7241
subcatchment_area [m^2]	207324000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2007 - 2013)

	Full year	**Summer**	**Winter**
RelErr	37.0 %	-13.8 %	75.8 %
NS	-0.529	-0.123	-0.893
NS_log	-0.792	-1.765	-1.304
NS_rel	-0.443	0.029	-1.796
KGE	0.339	0.18	0.012

Goodness of fit for validation period (all available period 2007 - 2013)

	Full year	**Summer**	**Winter**
RelErr	35.3 %	-15.7 %	74.7 %
NS	-0.5	-0.119	-0.863
NS_log	-0.776	-1.763	-1.283
NS_rel	-0.412	0.037	-1.744
KGE	0.347	0.168	0.016

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11ORN7241, station Orneau, Jemeppes-s-O (complete simulation period 1967-2013)

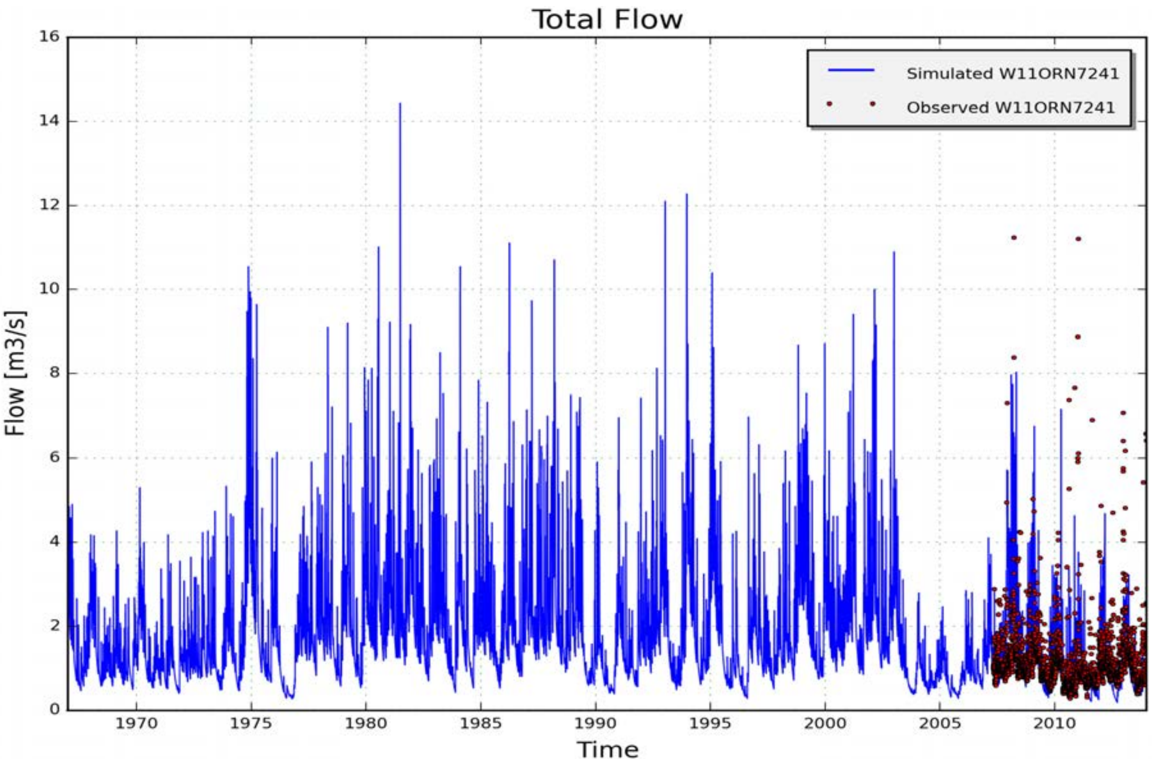


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11ORN7241, station Orneau, Jemeppes-s-O(calibration period)

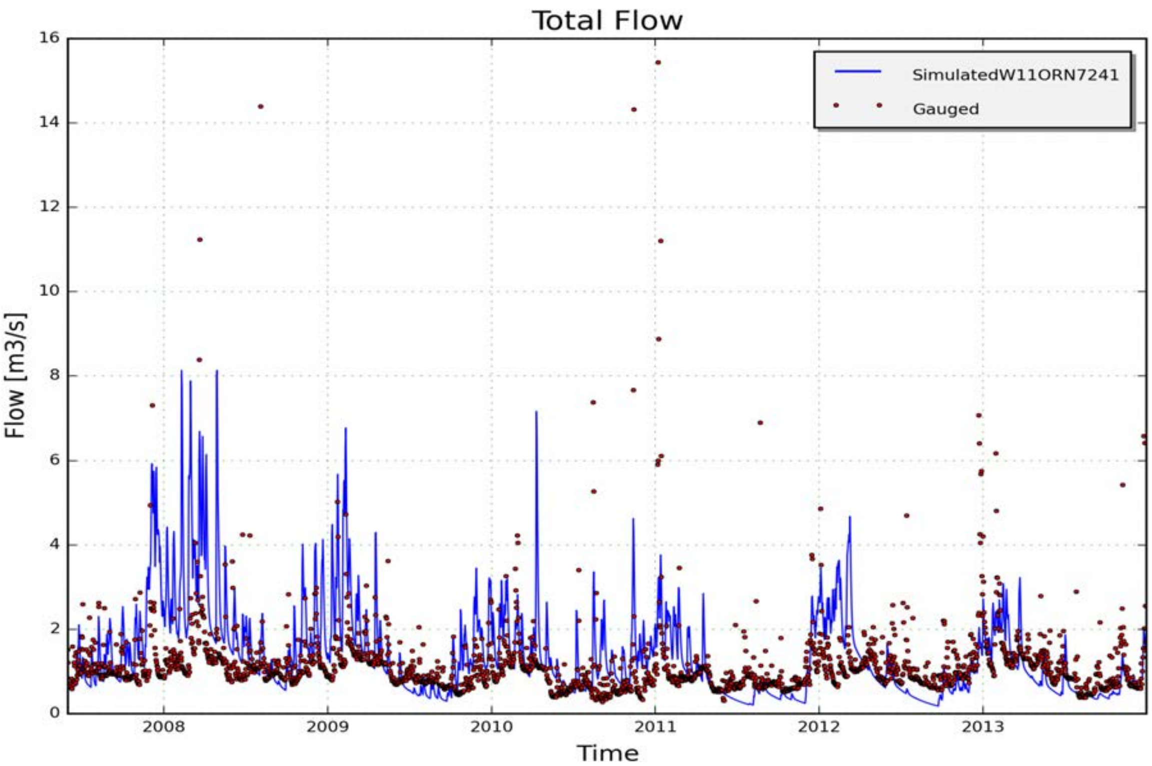


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11ORN7241, station Orneau, Jemeppes-s-O (calibration period)

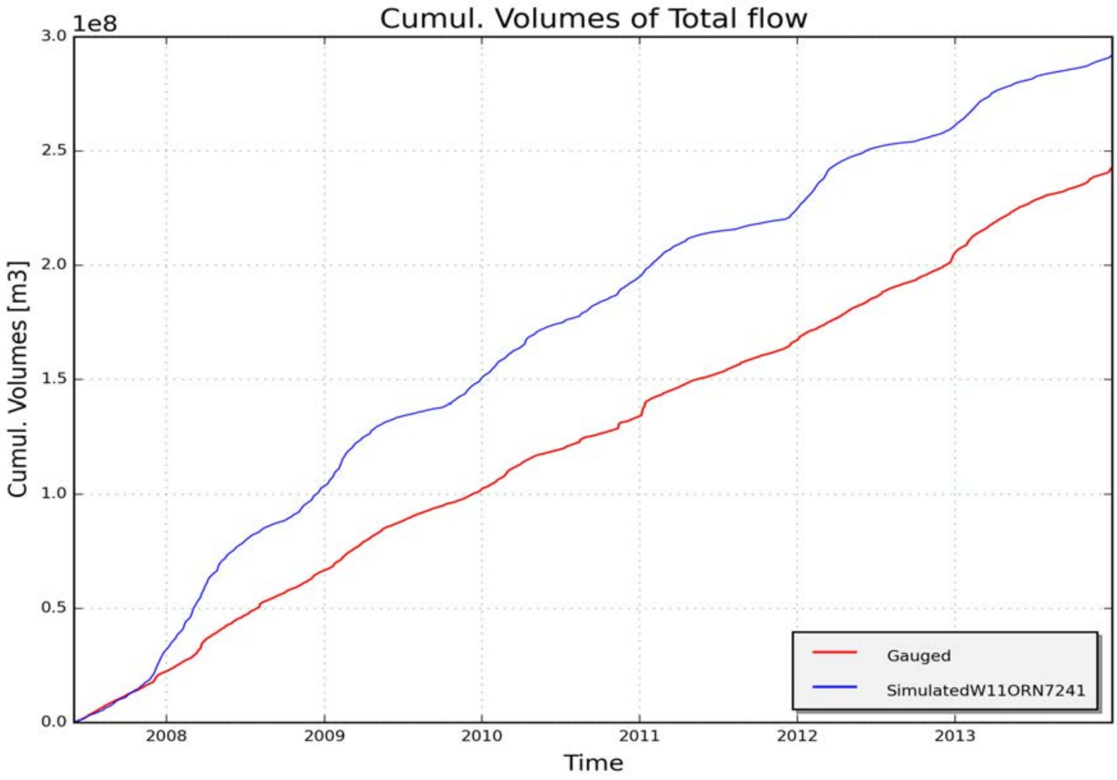


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11ORN7241, station Orneau, Jemeppes-s-O

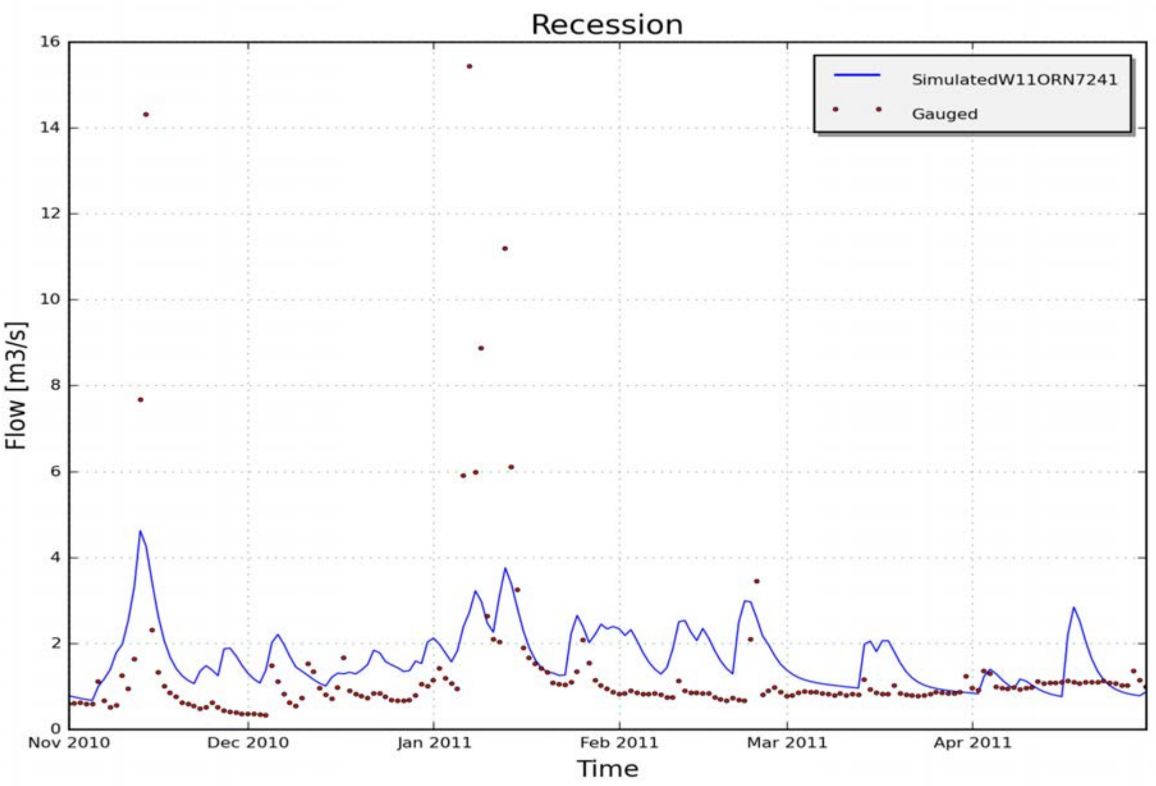
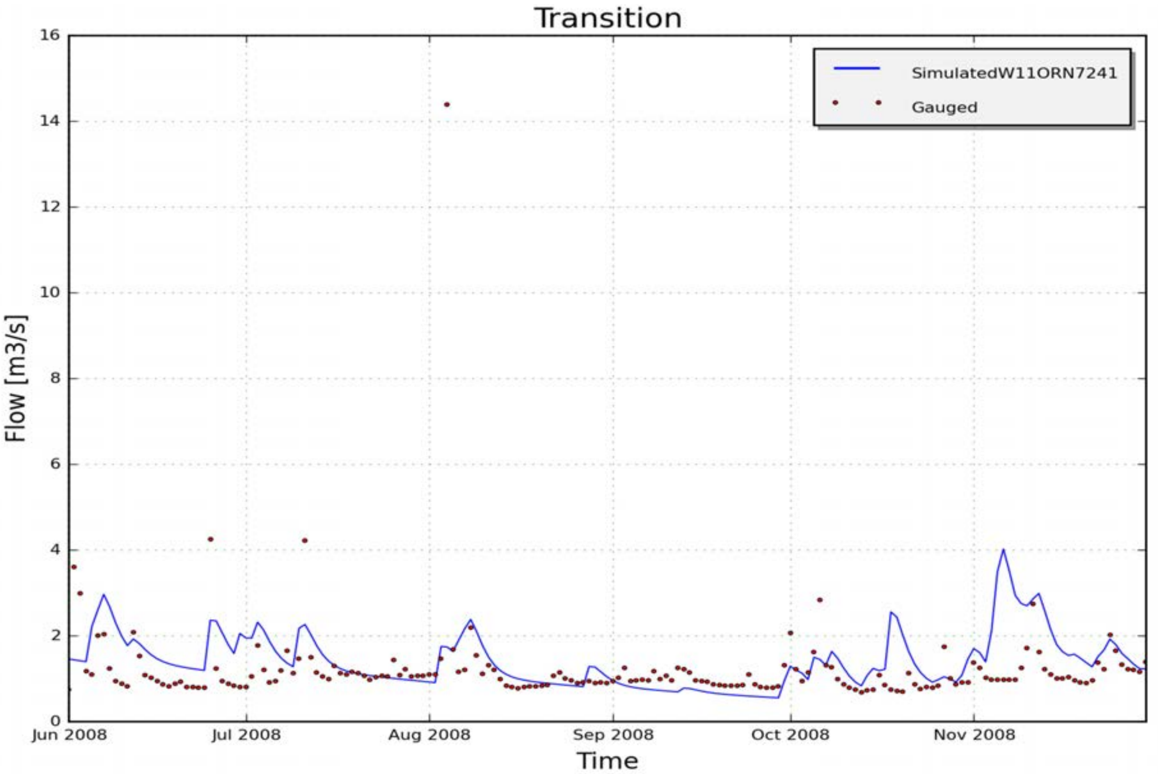


Figure 7 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11ORN7241, station Orneau, Jemeppes-s-O



Calibration and validation of NAM parameters for catchment "W11EDH7711" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11EDH7711 (Meuse)

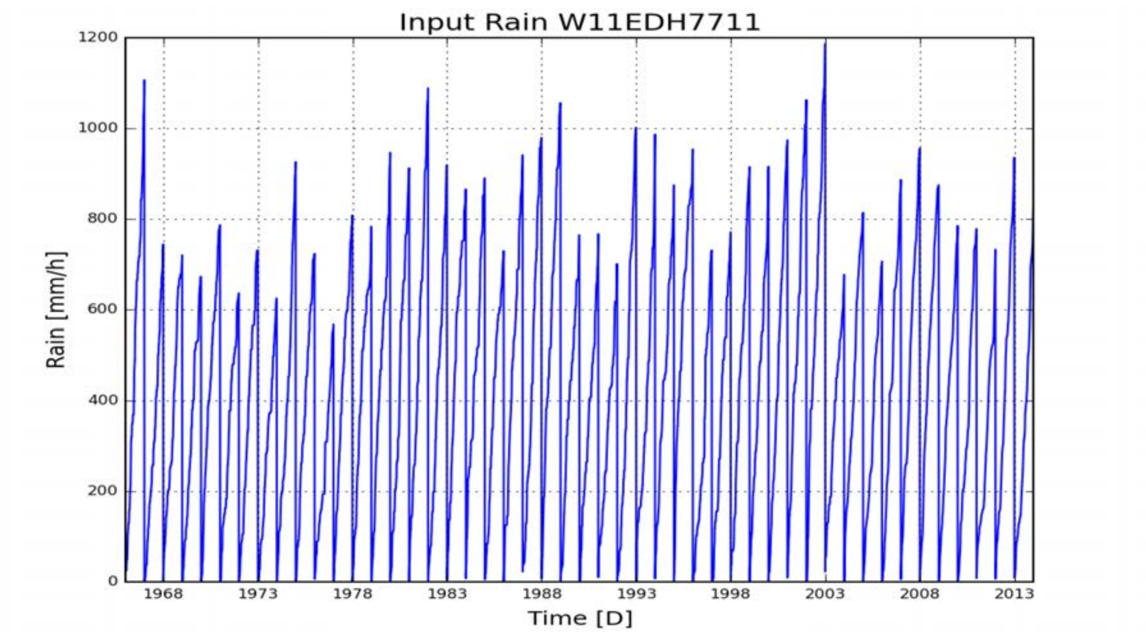
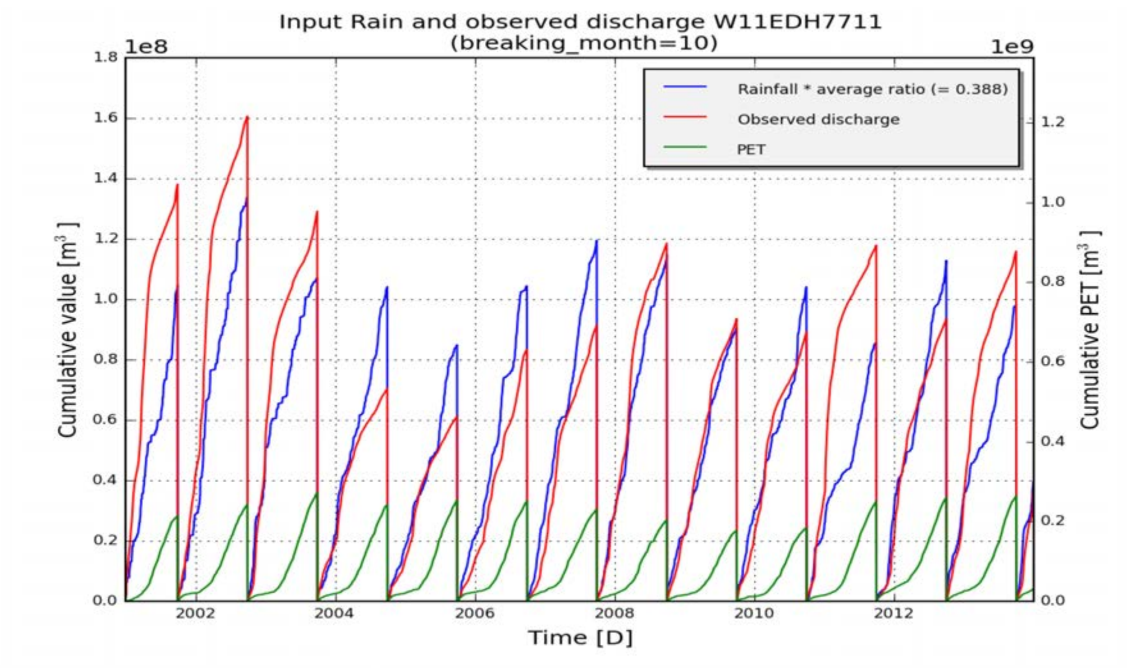


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11EDH7711 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11EDH7711
subcatchment_area [m^2]	323812000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	Summer	Winter
RelErr	-7.6 %	-4.0 %	-7.9 %
NS	0.626	-0.658	0.568
NS_log	0.248	-2.154	0.581
NS_rel	0.757	-0.214	0.76
KGE	0.664	0.349	0.578

Goodness of fit for validation period (all available period 1995 - 2013)

	Full year	Summer	Winter
RelErr	-5.2 %	4.2 %	-11.0 %
NS	0.647	-0.349	0.621
NS_log	0.343	-1.794	0.66
NS_rel	0.727	-0.059	0.754
KGE	0.688	0.432	0.609

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11EDH7711, station Eau d'Heure, Jamioulx (complete simulation period 1967-2013)

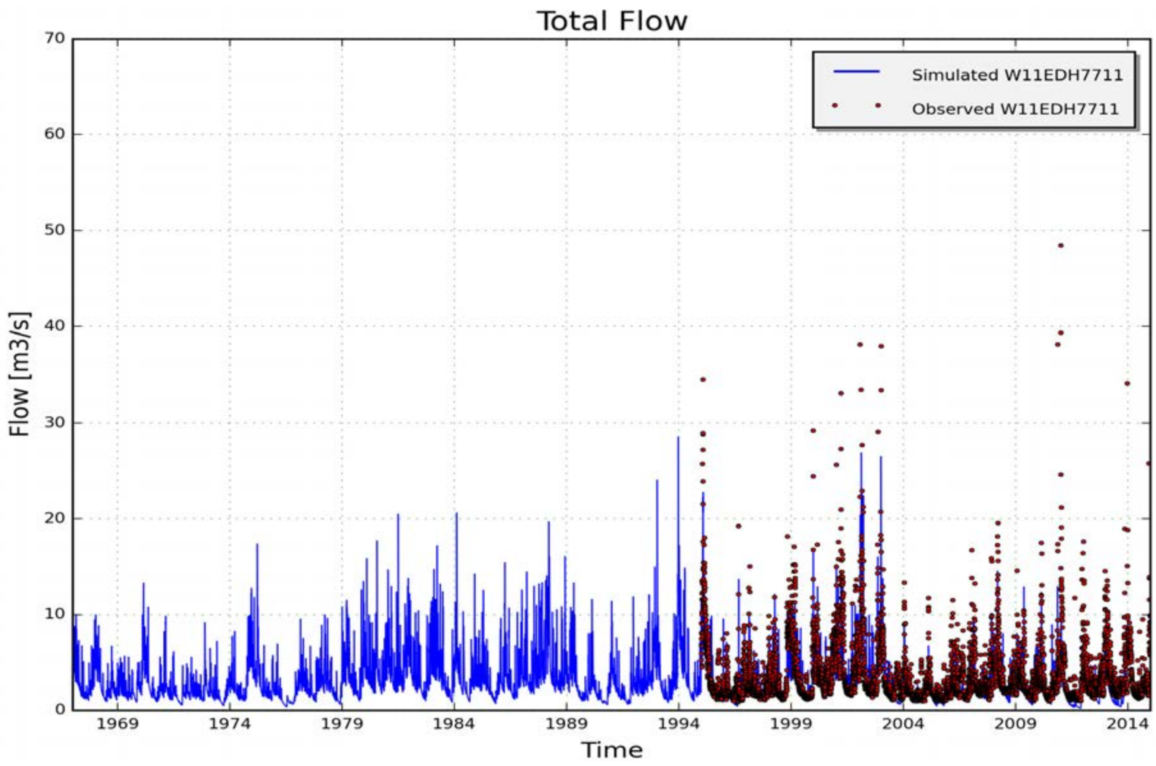


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11EDH7711, station Eau d'Heure, Jamioulx(calibration period)

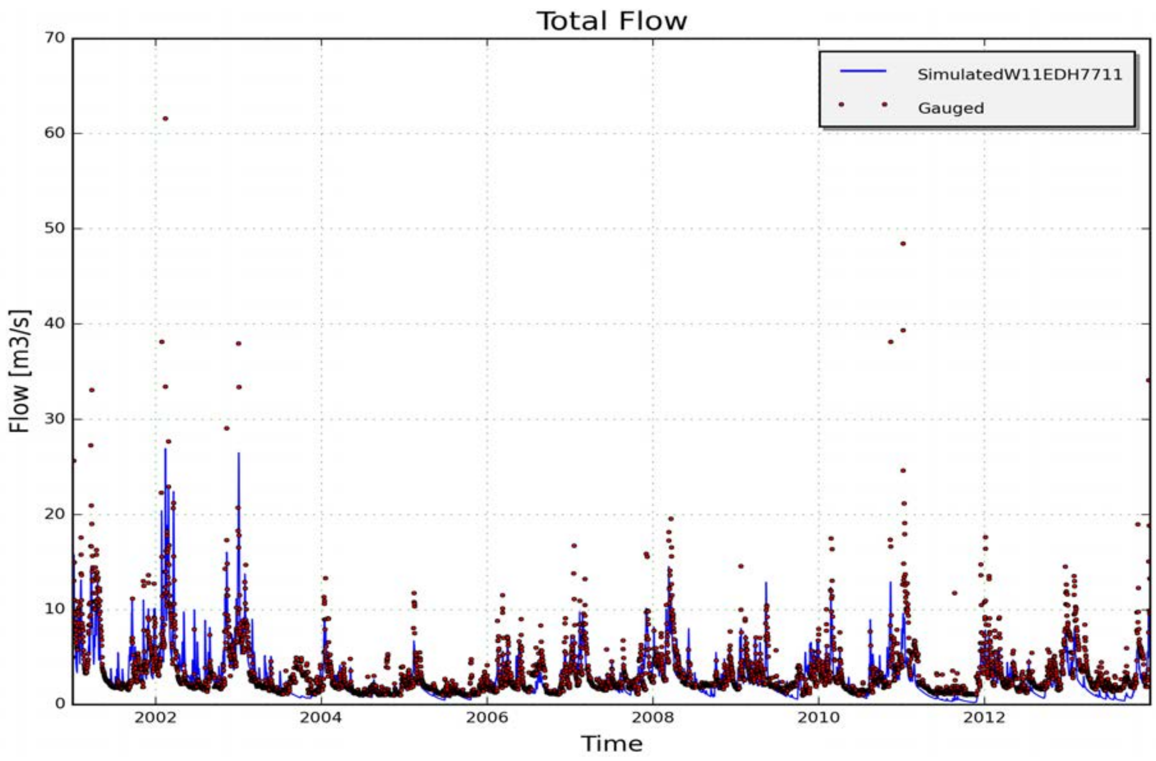


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11EDH7711, station Eau d'Heure, Jamioulx (calibration period)

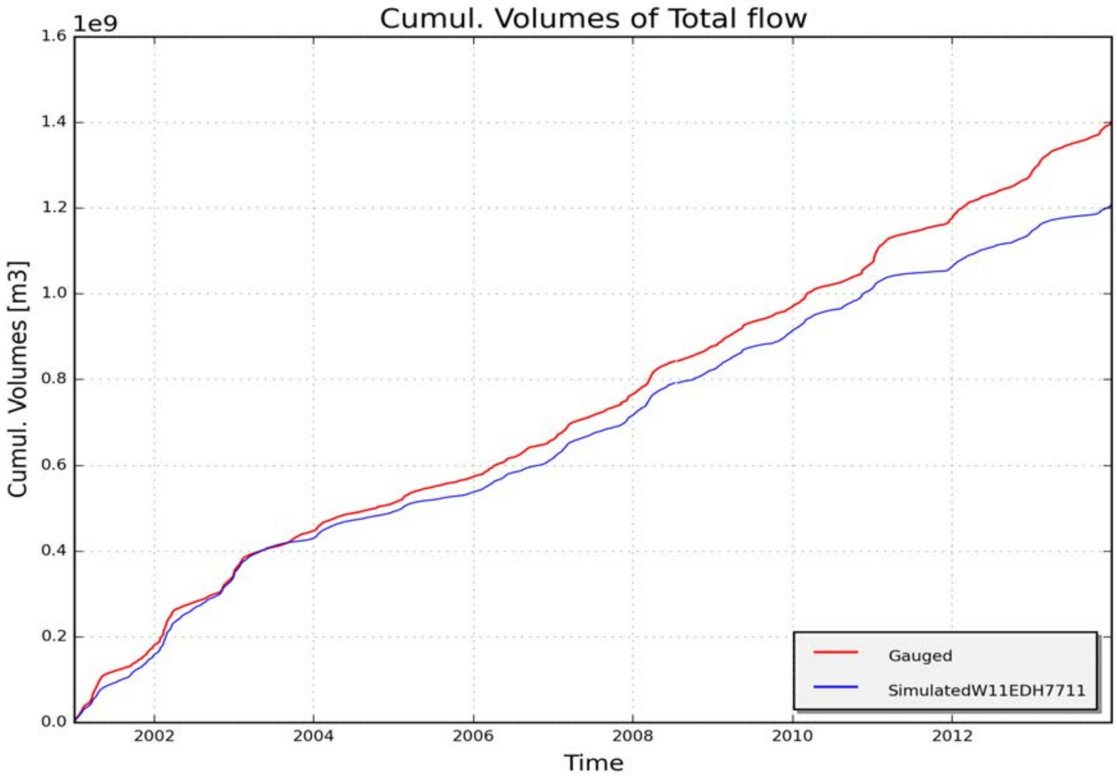
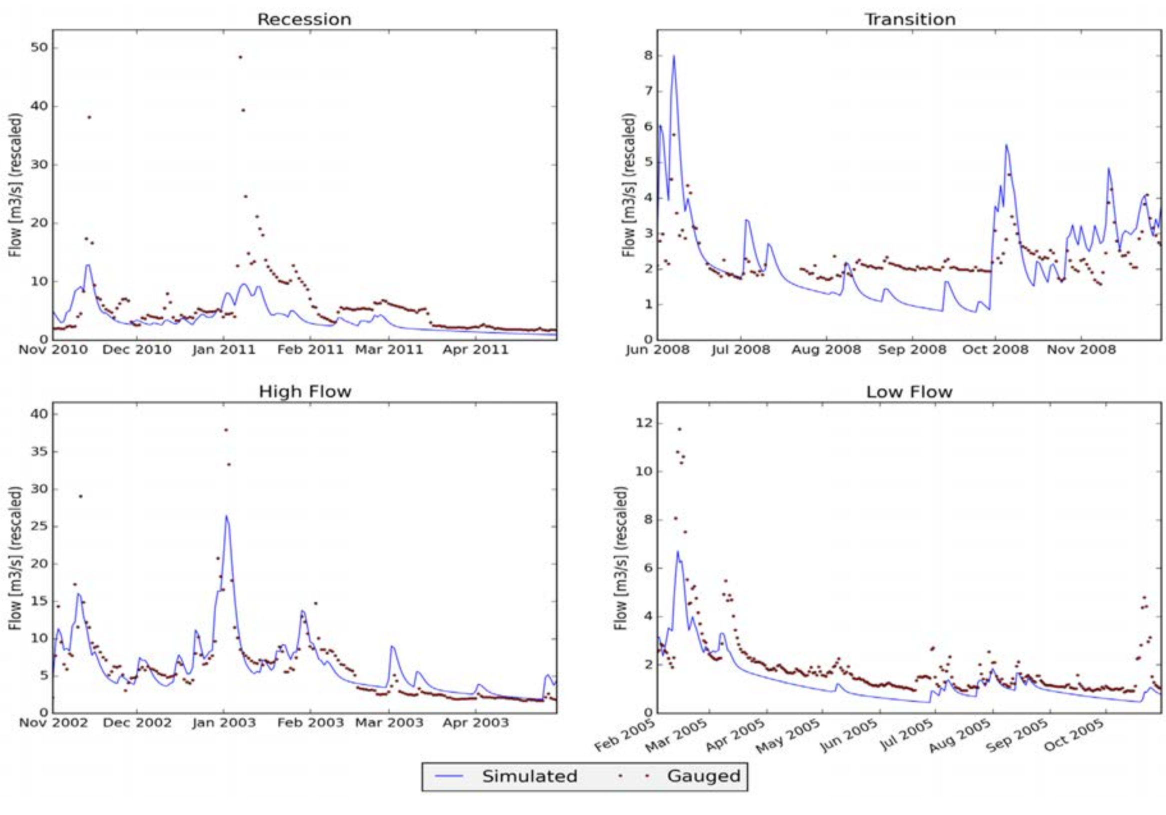


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11EDH7711, station Eau d'Heure, Jamioulx



Calibration and validation of NAM parameters for catchment "W11HAN7944" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment W11HAN7944 (Meuse)

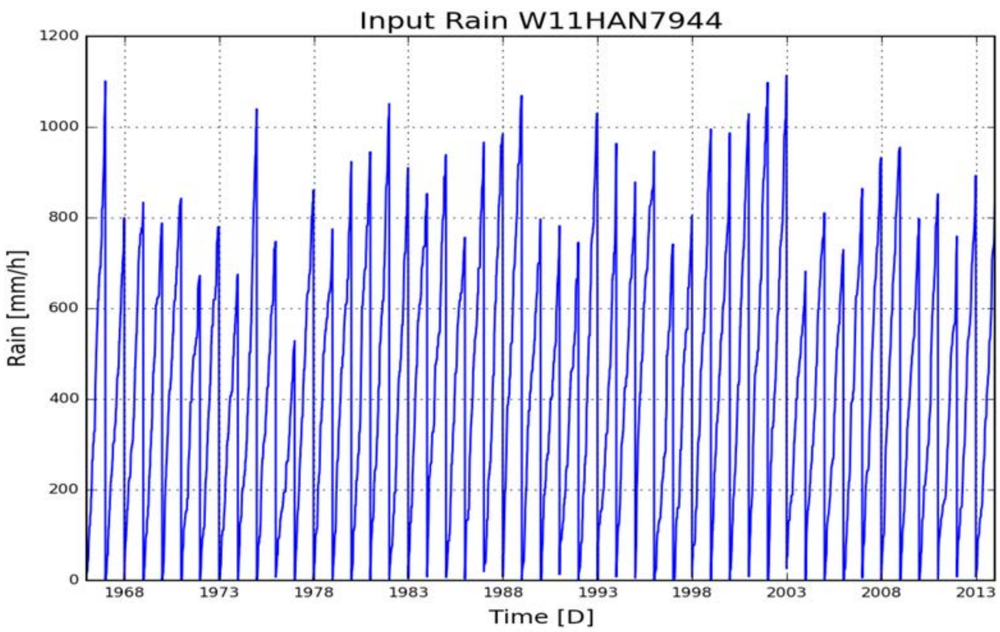
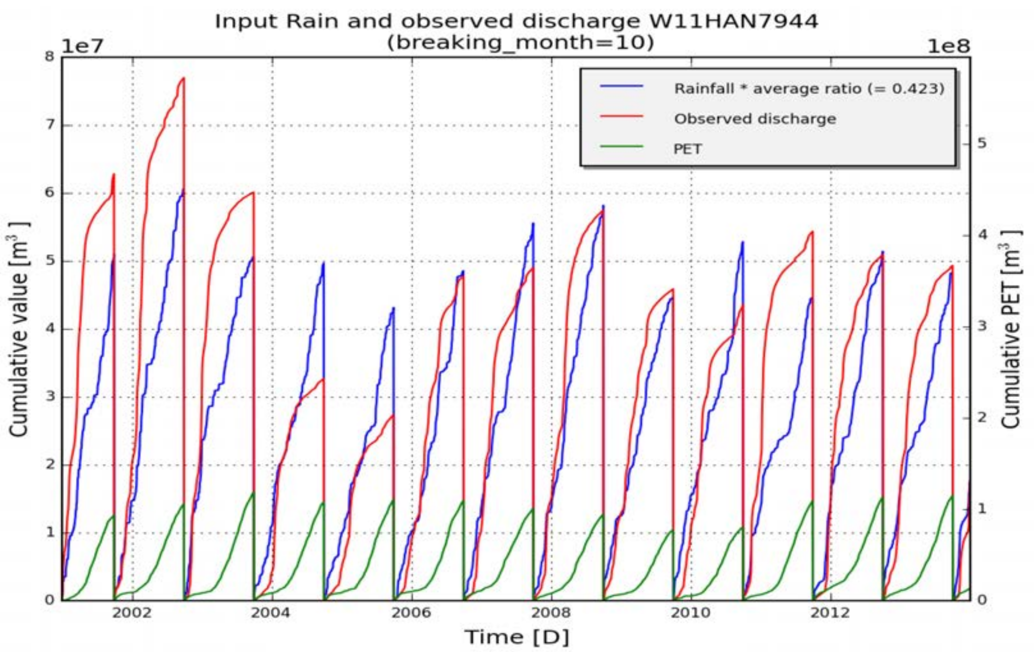


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment W11HAN7944 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	W11HAN7944
subcatchment_area [m^2]	141344000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-12.5 %	77.6 %	-32.8 %
NS	0.519	0.097	0.348
NS_log	0.676	-0.474	0.573
NS_rel	0.685	-0.066	0.85
KGE	0.391	0.283	0.248

Goodness of fit for validation period (all available period 1985 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-4.4 %	79.9 %	-25.5 %
NS	0.566	0.197	0.437
NS_log	0.648	-0.397	0.671
NS_rel	0.541	0.058	0.74
KGE	0.449	0.197	0.325

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HAN7944, station Hantes, Wiheries (complete simulation period 1967-2013)

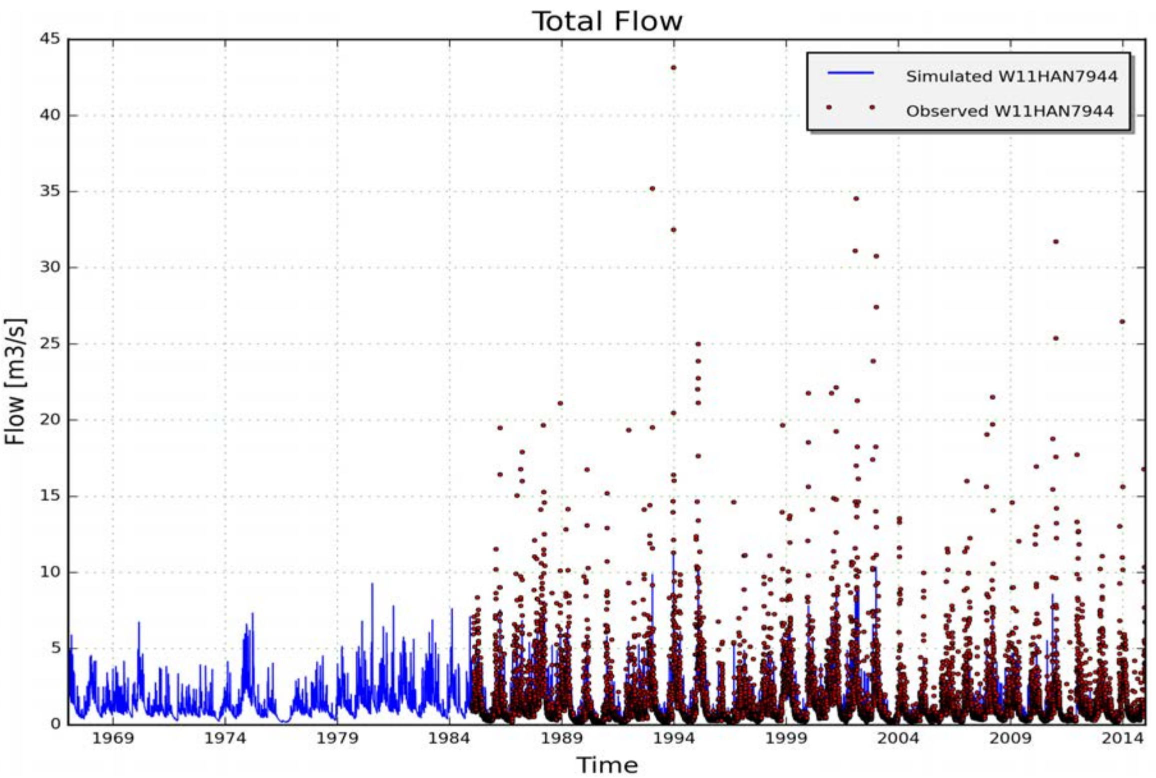


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment W11HAN7944, station Hantes, Wiheries(calibration period)

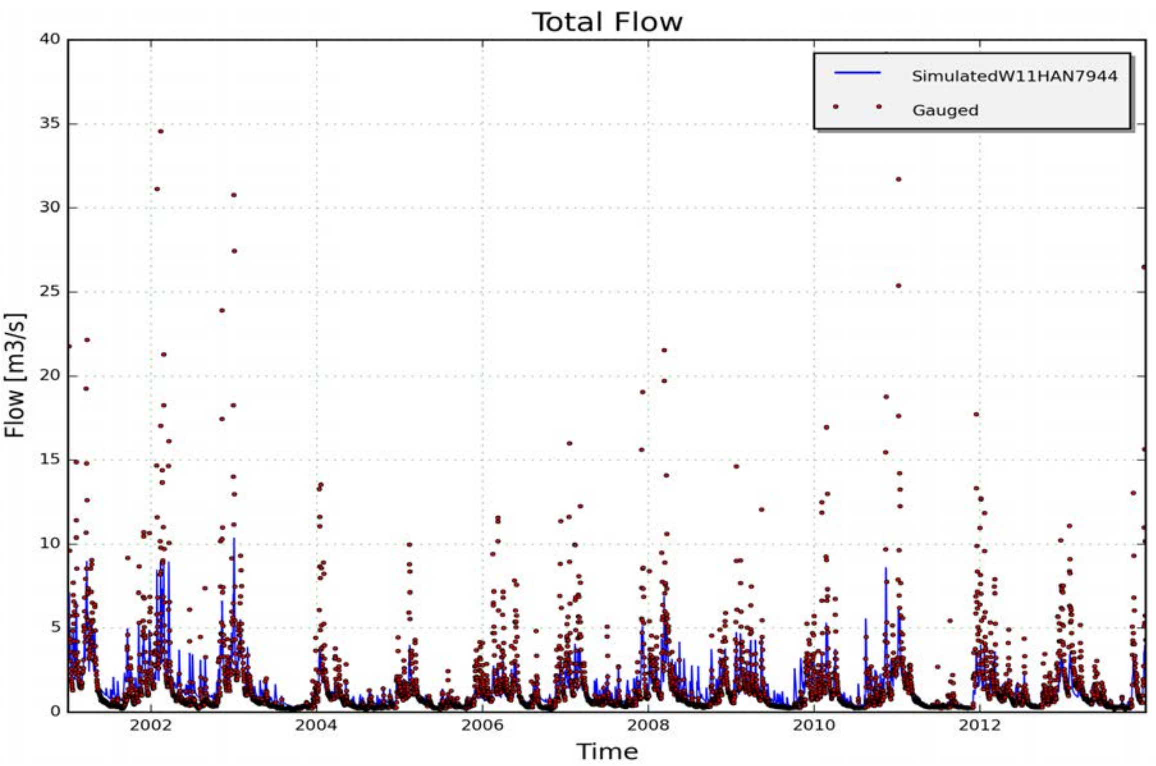


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment W11HAN7944, station Hantes, Wiheries (calibration period)

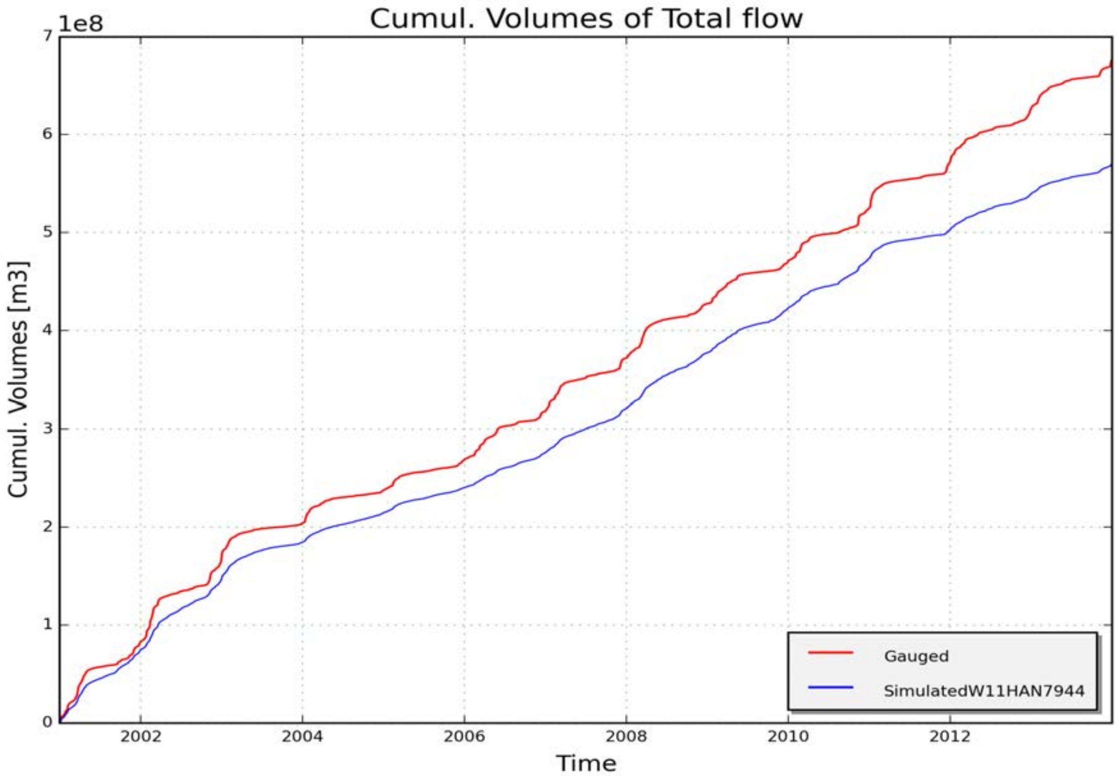
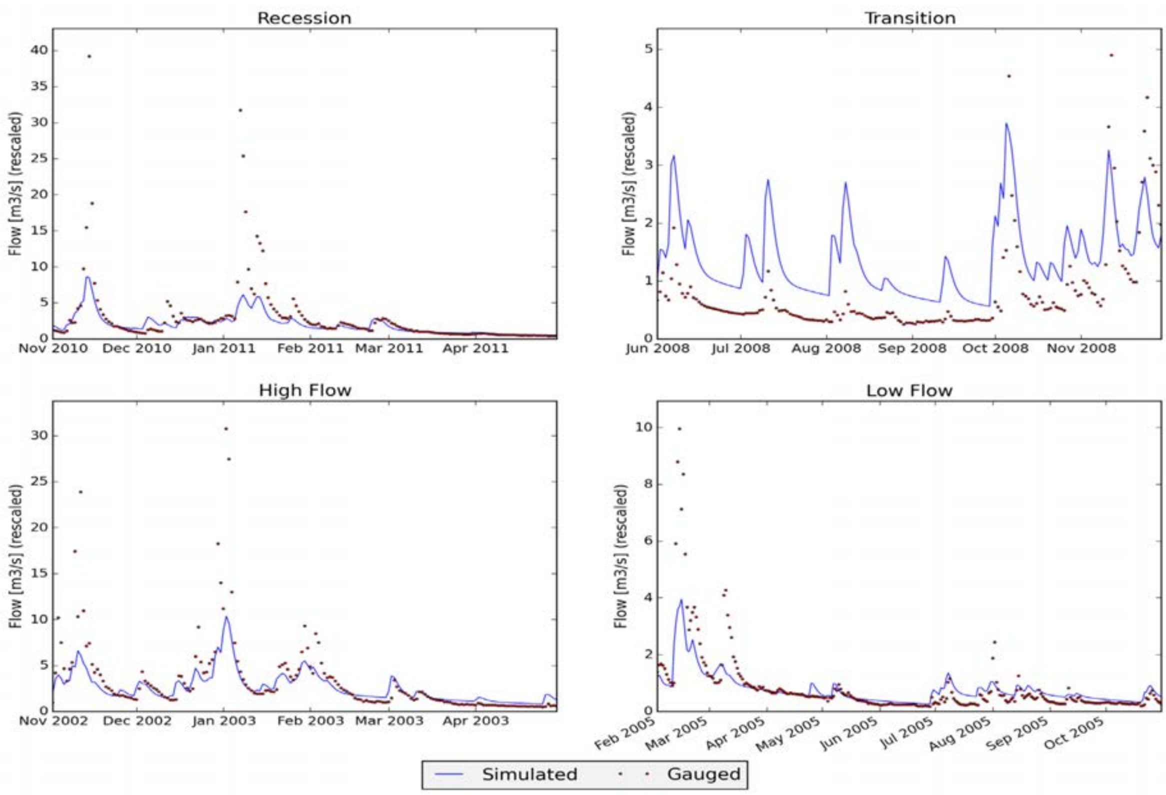


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment W11HAN7944, station Hantes, Wiheries



Calibration and validation of NAM parameters for catchment "F11SAM7487" (Meuse)

Input data

Figure 1 – Cumulative precipitation on catchment F11SAM7487 (Meuse)

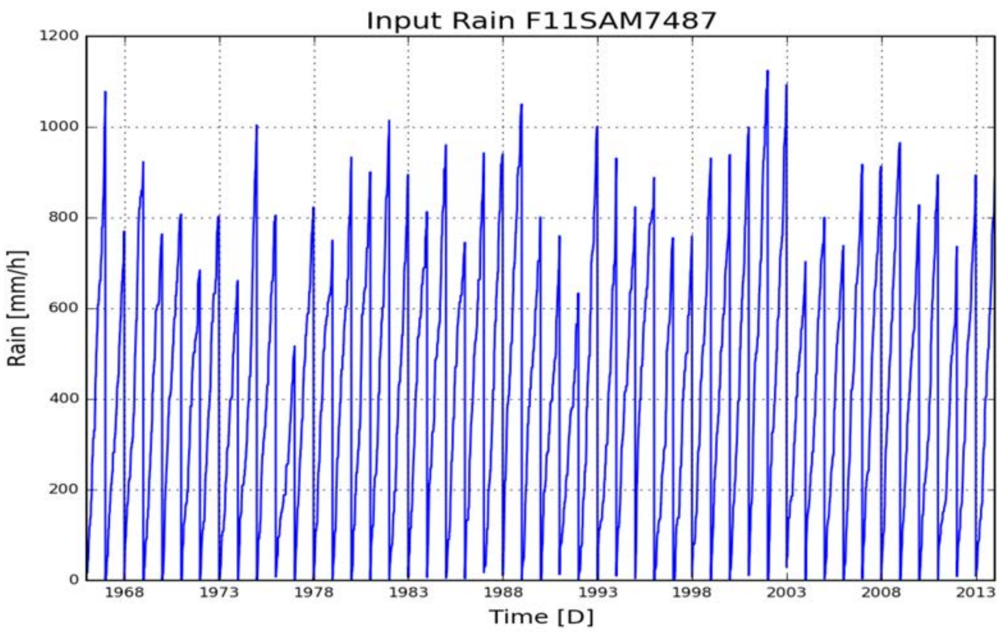
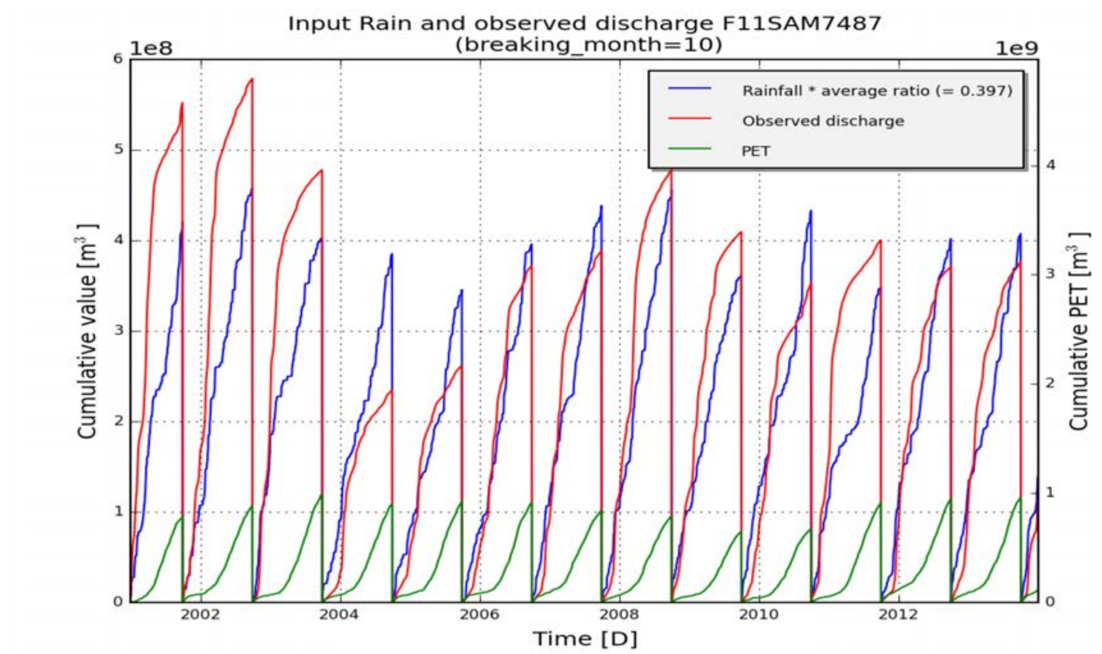


Figure 2 – Annual cumulated discharge (red) and scaled precipitation (blue) according to runoff ratio (total Q/total P) and cumulative potential evapotranspiration (green) on catchment F11SAM7487 (Meuse)



Model summary

model_structure	NAMclassic.Lumped
subcatchment_name	F11SAM7487
subcatchment_area [m^2]	1181000000
start_date	01-01-1967
end_date	31-12-2013
frequency	daily

Optimal parameter set:[('Umax.C', 4.7), ('SMmax.C', 437.0), ('CQOF.C', 0.68), ('CKBF.C', 1680.0), ('CKIF.C', 245.0), ('CK1.C', 26.0), ('CK2.C', 48.0), ('TIF.C', 0.9), ('TOF.C', 0.32), ('NAM.TG.C', 0.01)]

Goodness of fit for calibration period (2001 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-5.3 %	82.2 %	-26.0 %
NS	0.638	-0.487	0.474
NS_log	0.669	-0.724	0.651
NS_rel	0.628	-0.739	0.799
KGE	0.534	0.161	0.398

Goodness of fit for validation period (all available period 1998 - 2013)

	Full year	**Summer**	**Winter**
RelErr	-7.6 %	79.7 %	-27.6 %
NS	0.635	-0.475	0.464
NS_log	0.68	-0.696	0.658
NS_rel	0.617	-0.755	0.797
KGE	0.523	0.17	0.39

Observed and simulated timeseries for optimum parameters

Figure 3 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment F11SAM7487, station Samber, Sorle (complete simulation period 1967-2013)

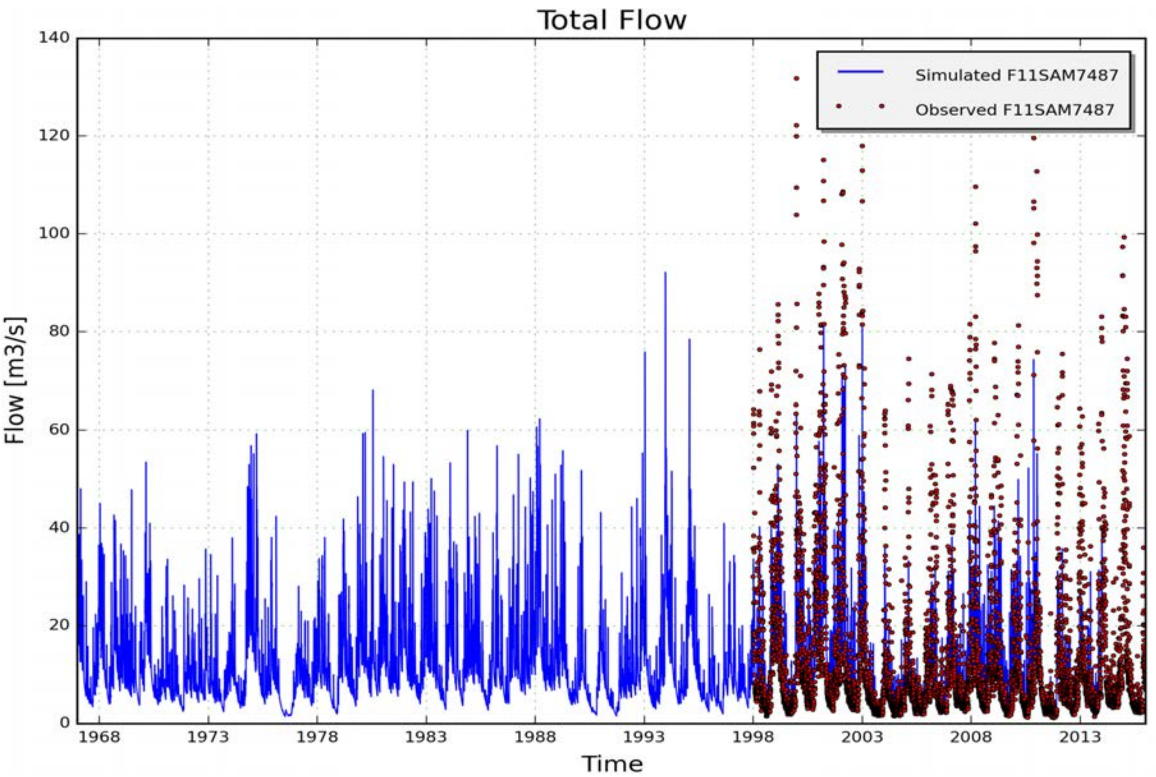


Figure 4 – Measured (red) and simulated (blue) daily discharge [m3/s] on catchment F11SAM7487, station Samber, Sorle(calibration period)

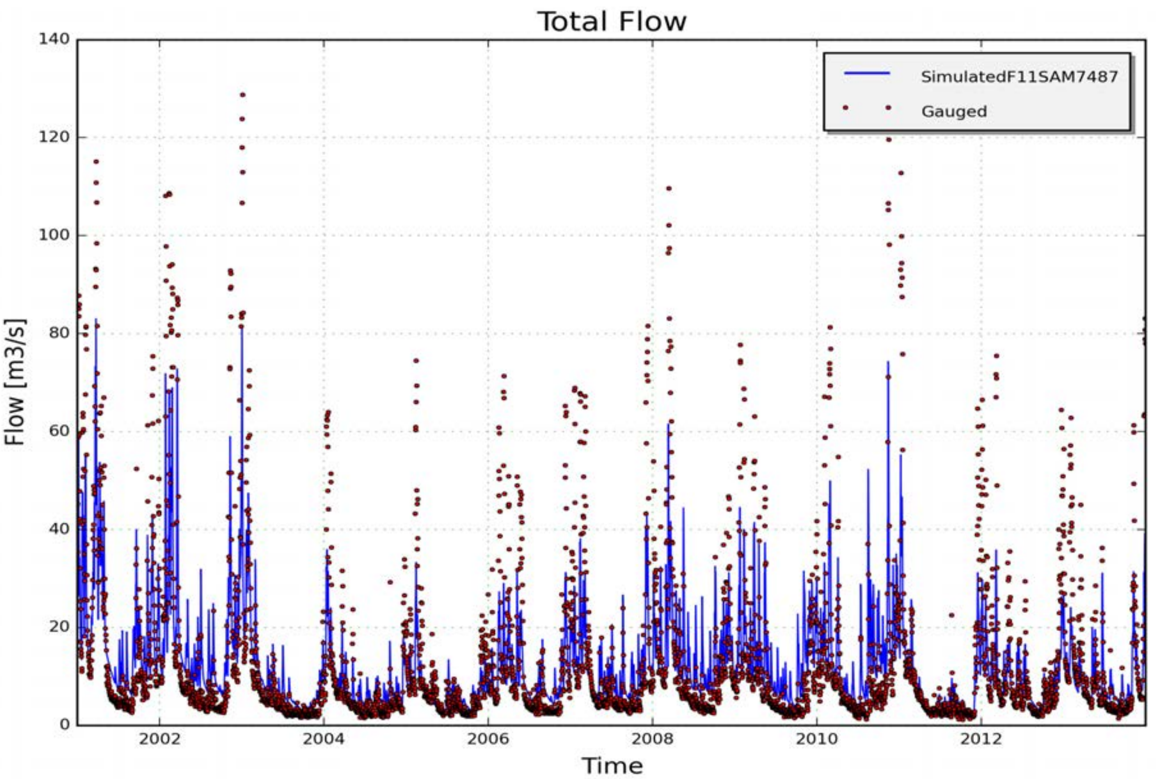


Figure 5 – Measured (red) and simulated (blue) cumulative discharge [m3] on catchment F11SAM7487, station Samber, Sorle (calibration period)

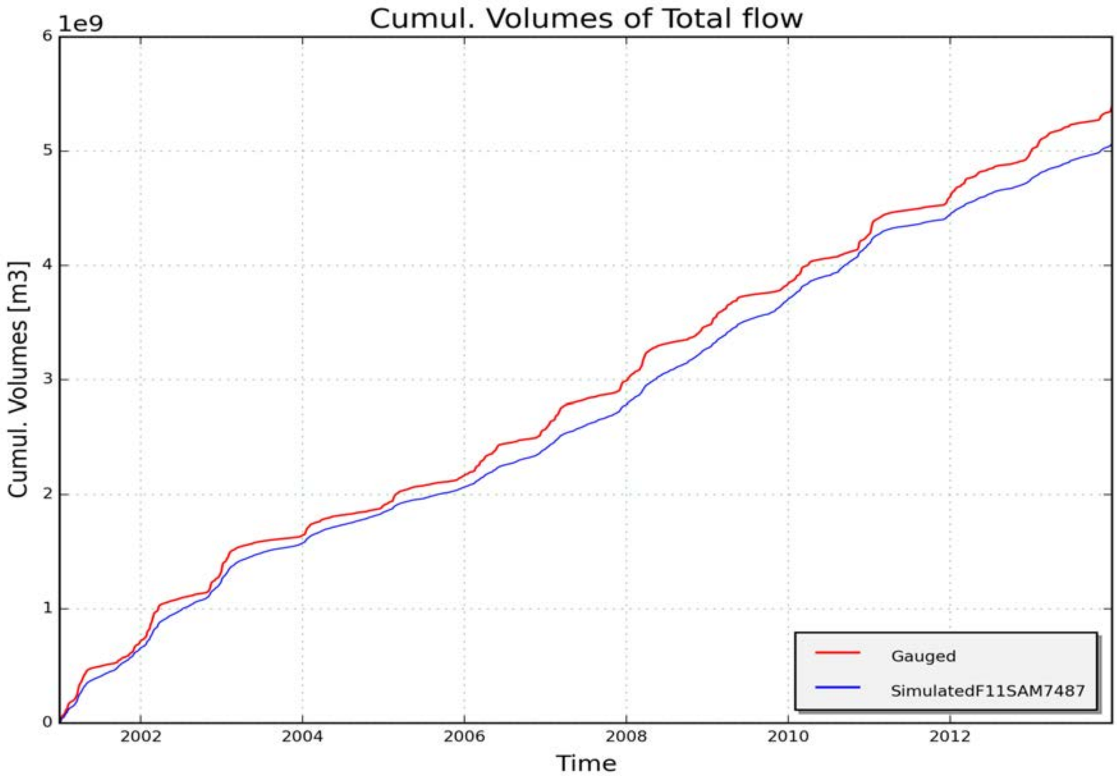
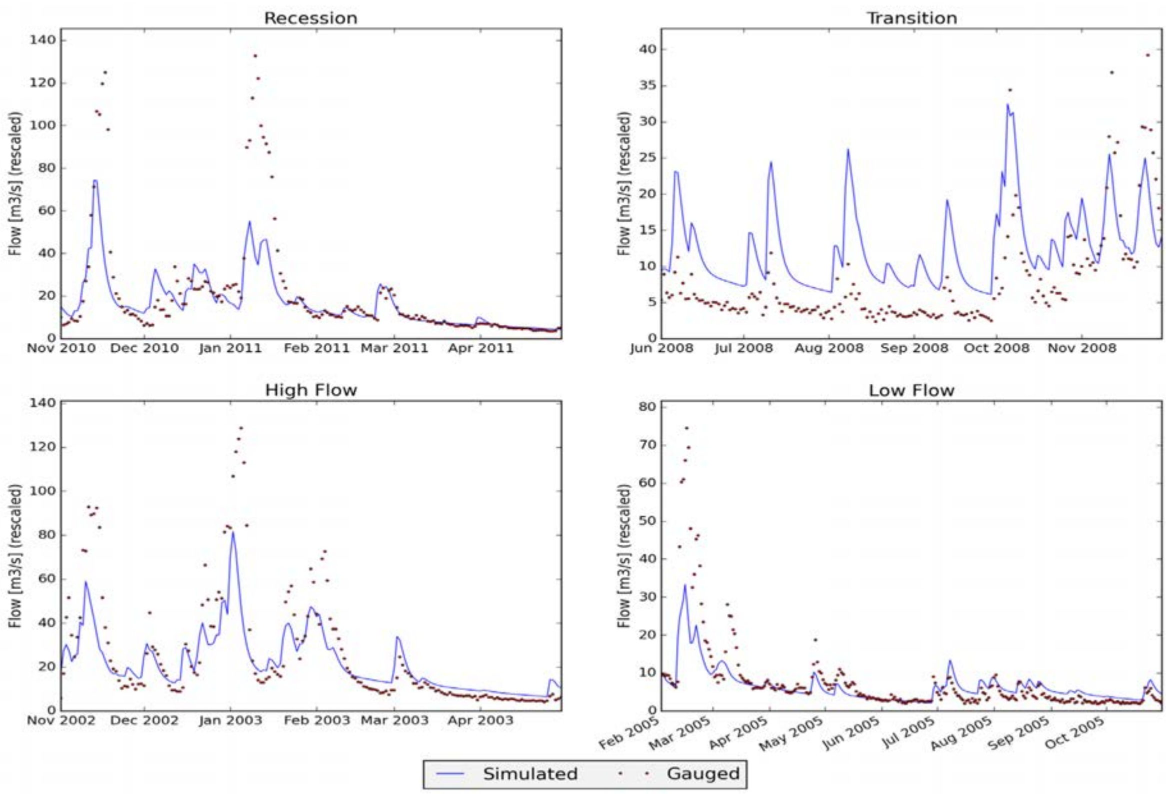


Figure 6 – Measured (red) and simulated (blue) daily discharge [m3/s] during specific low and high flow events on catchment F11SAM7487, station Samber, Sorle



DEPARTMENT **MOBILITY & PUBLIC WORKS**
Flanders hydraulics Research

Berchemlei 115, 2140 Antwerp
T +32 (0)3 224 60 35
F +32 (0)3 224 60 36
waterbouwkundiglabo@vlaanderen.be
www.flandershydraulicsresearch.be