Comparative Analysis of the Runoff-Generation Using Lumped and Distributed Approaches, with Application to the Jeker Catchment in Belgium

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ABSTRACT

This poster presents 2 different methods for predicting the rainfall-runoff that increases gradually in complexity. The methods applied in this study are (1) a lumped semi-empirical method, being the NAM-module of the MIKE 11 model, and (2) a fully distributed, physically-based deterministic catchment model, the MIKE SHE model. The two methods are applied to the river Jeker basin, situated in the loamy belt region of Belgium. The size of the catchment area is 465 km^2. The landscape is rolling, and the soils are varying from sandy-loam to clay-loam. The soils are deep, and the phreatic aquifer is at a depth of 4 to 50 m below the surface. The hourly data of a continuous period of 6 years are used for the calibration and validation of the 2 different models.
The model performance is tested with respect to the model ability in simulating peak flows.

INTRODUCTION

The correct estimation of the runoff volume towards river draining catchments is an important issue in hydrology, particularly for conditions of highly intense rainfall, long-duration low-intensity rainfall, snowmelt, failure of dam or levee systems, or combinations of these conditions. It is often the basis for the planning, design and management of river and flood protection works. The choice of the method to be used for the assessment of the design flood is the first step in the proper handling of floods.

Several papers were dedicated towards comparison between two or more hydrological models. Loague and Freeze (1985) included comparison of

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distributed physically based models (Quasi) with simpler black box models (Regression and Unit hydrograph models). Michaud and Sorooshian (1994) compared a lumped conceptual model (SCS) with a distributed physically based model (KINEROS). Refsdaard and Knudsen (1996) validated and compared three different models on three catchments, a lumped conceptual modelling system (NAM), a distributed physically based system (MIKE SHE) and an intermediate approach (WATBAL). Yet each has used different approach to validate the results of the different models. In this paper the typical split-sample test (SS) was applied and a set of well-known performance criteria were applied, in addition to a typical extreme peak value analysis.

Many authors tend to critique the use of distributed models; their main concern is the many parameters that can be altered during the calibration phase. Beven (1989, 1996) considers models which are usually claimed to be distributed physically based as in fact being lumped conceptual models, just with more parameters. According to Beven (1996) a key characteristic of the distributed model is that “the problem of overparameterisation is consequently greater”. In response, Refsgaard and Storm (1996) emphasize that a rigorous parameterisation procedure is crucial in order to avoid methodological problems in the subsequent phases of model calibration and validation.

MATERIALS AND METHODS

1. Theory of the two models

❖ *The NAM Module (MIKE 11 Model)*

NAM forms part of the rainfall module of the MIKE 11 river modelling system (Havnø et al., 1995). It can be characterised as a deterministic, lumped, conceptual model with moderate input data requirements. It consists of set of linked mathematical statements describing, in a simplified quantitative form, the behaviour of the land phase of the hydrological cycle. NAM represents various components of the land phase of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storage (Figure 1). Each storage represents different physical elements of the catchment. These storages are:

- Snow storage
- Surface storage
- Lower or root zone storage
- Groundwater storage

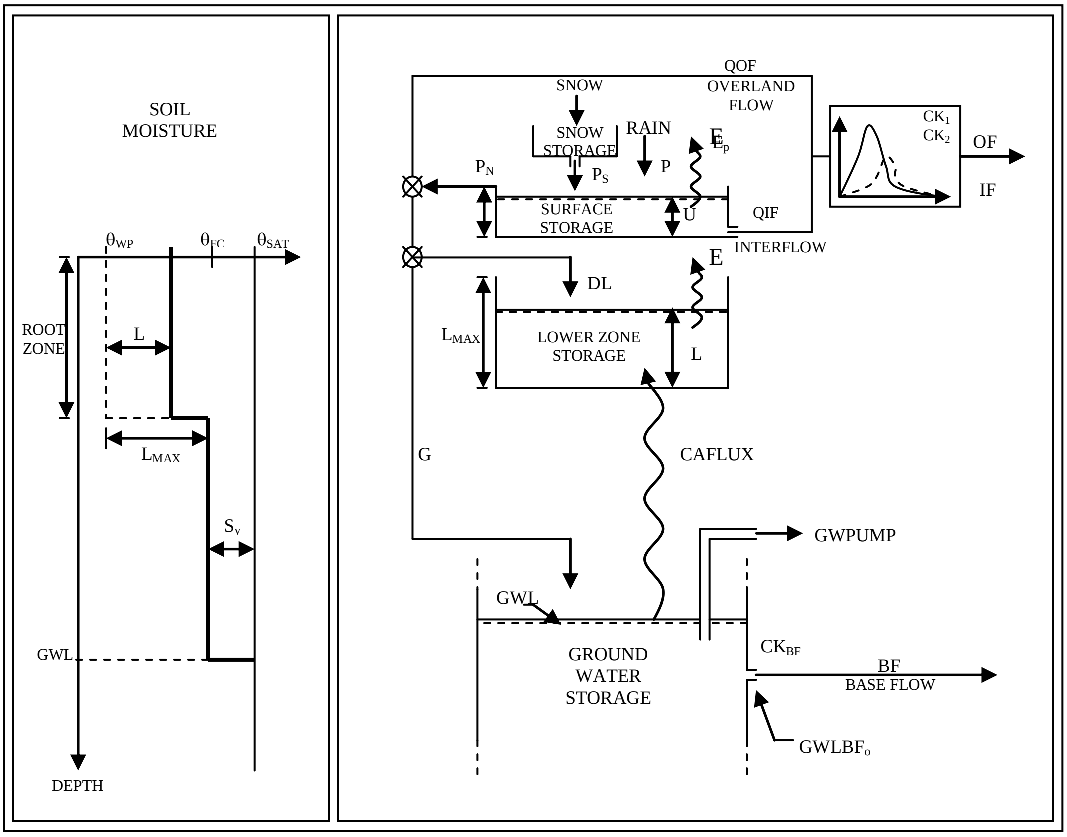


Figure 1: Structure of the NAM model

❖ *The MIKE SHE Model*

MIKE SHE (Refsgaard & Storm, 1995) is a deterministic physically-based distributed model for the simulation of the hydrological processes of the land phase of the hydrological cycle, with obvious large amount of input data.

The SHE model was developed to model the spatial distribution of basin parameters, hydro-meteorological inputs and hydrological response in 3 dimensional form. This means that it represents the basin horizontally by an orthogonal grid network and it uses a vertical column at each horizontal grid square (Figure 2). The finite difference technique is used in SHE model to model the various hydrological processes. Actually, in the SHE model, the partial differential equations for the conservation of mass, momentum and energy are solved by the usage of the finite element technique in addition to some empirical equations.

The major processes (components) of the hydrological cycle represented by the model are:

- canopy interception
- evapotranspiration
- snow melt
- channel flow
- overland flow
- unsaturated flow
- saturated flow

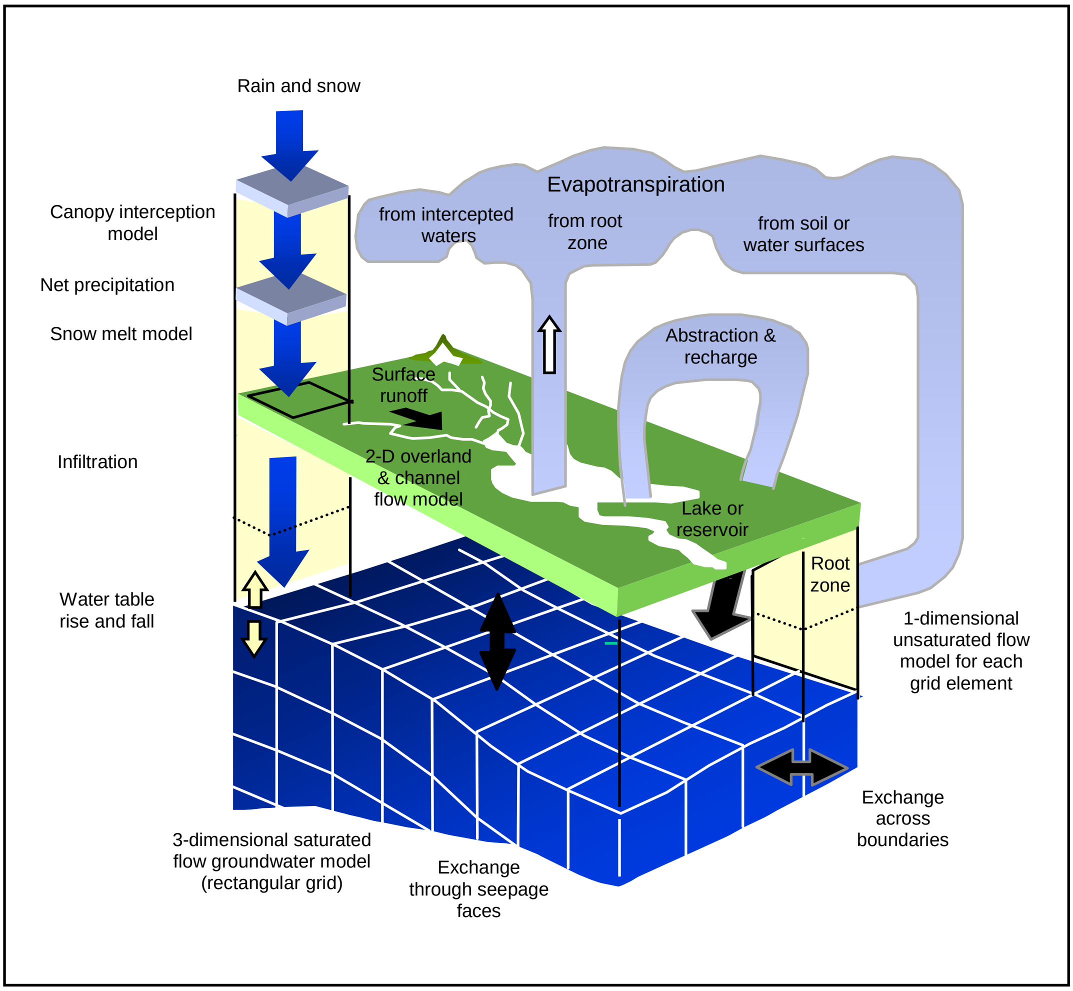


Figure 2: Schematic Structure of the WM module of MIKE SHE

Lumped & Distributed Approaches

Being a lumped model, NAM treats the catchment as a single unit. The parameters and variables represent, therefore, average values for the entire catchment. As a result some of the model parameters can be evaluated from physical catchment data, but the final parameter estimation must be performed by calibration against time series of hydrological observations.

On the contrary MIKE SHE is a distributed hydrological model structured to enable the spatial variations in catchment characteristics to be represented by providing data for a network of grid points, each of them is characterised by several parameters and variables (Refsgaard, 1997). This implies that the MIKE SHE with regard to MIKE 11 needs more requirements with regard to parameterisation, calibration and validation procedures

2. Study Area

The Jeker catchment (465 KM^2), which is located at the middle of Belgium, was chosen for the model application (Figure 3).

Out of three available discharge stations the main discharge station at the downstream end of the catchment (Kanne) was chosen to compare between the two model outputs with respect to the observed discharge. A time series of continuous data (i.e. discharge, rainfall…etc) for 6 years were utilised in a standard split sample (SS) test.

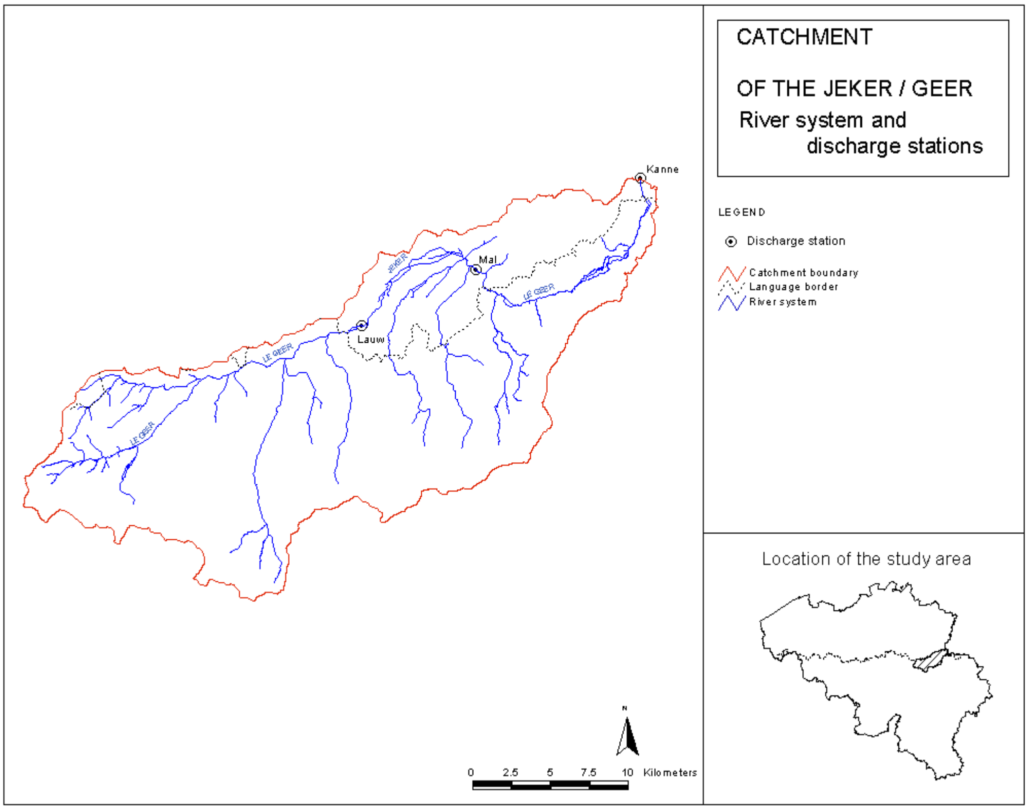


Figure 3: Location of the study area & river network and the discharge stations

3. Performance Criteria

Different performance criteria were utilised to perform the analysis on the river discharge at the basin outlet station. This includes:

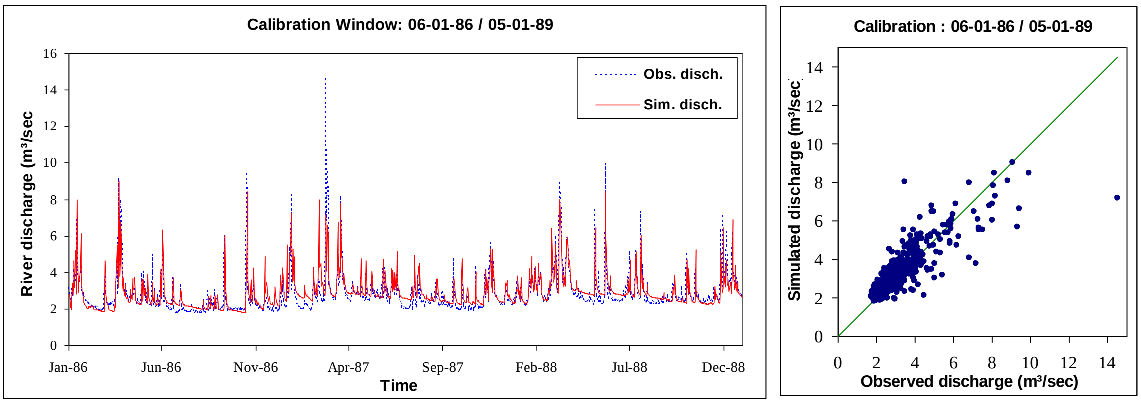
- Good Agreement between simulated and observed river discharge in the two split sample conditions (Calibration & Validation) as hydrographs and scatter plots;
- Quantitative evaluation by set of well known statistical performance indices (Gupta et al., 1998) and (Vazquez et al., 1999): Root Mean Square Error

(RMSE), Mean Absolute Error (MAE), Coefficient of Determination (CD), Modelling Efficiency (EF) and Goodness of Fit (R^2);

- Examination for the model long-run prediction of the high peaks through extreme peak value analysis.

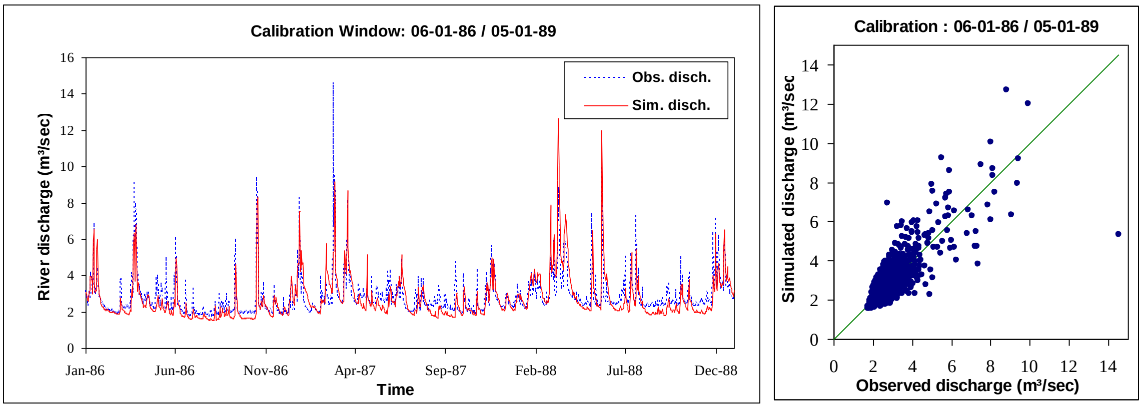
RESULTS & DISCUSSION

➢ Agreement between observed and simulated discharges, Figures 4, 5, 6 & 7.



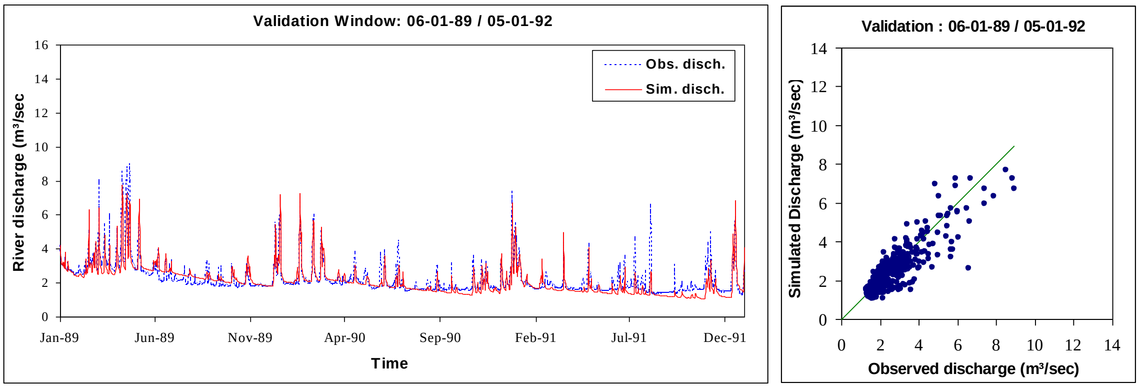
(a) *(b)*

Figure 4: Observed and Simulated river flow at the main limnigraphic station (Kanne) as: (a) Flow hydrograph, (b) Scattered plot, for the Calibration period using MIKE 11



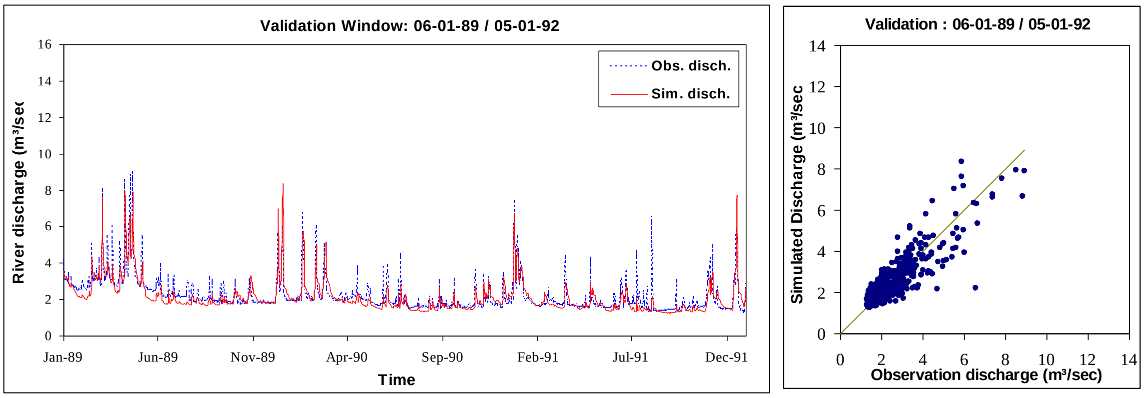
(a) *(b)*

Figure 5: Observed and Simulated river flow at the main limnigraphic station (Kanne) as: (a) Flow hydrograph, (b) Scattered plot, for the Calibration period using MIKE SHE



(a) *(b)*

Figure 6: Observed and Simulated river flow at the main limnigraphic station (Kanne) as: (a) Flow hydrograph, (b) Scattered plot, for the Validation period using MIKE 11



(a) *(b)*

Figure 7: Observed and Simulated river flow at the main limnigraphic station (Kanne) as: (a) Flow hydrograph, (b) Scattered plot, for the Validation period using MIKE SHE

➢ Statistical performance indices results (Table 1)

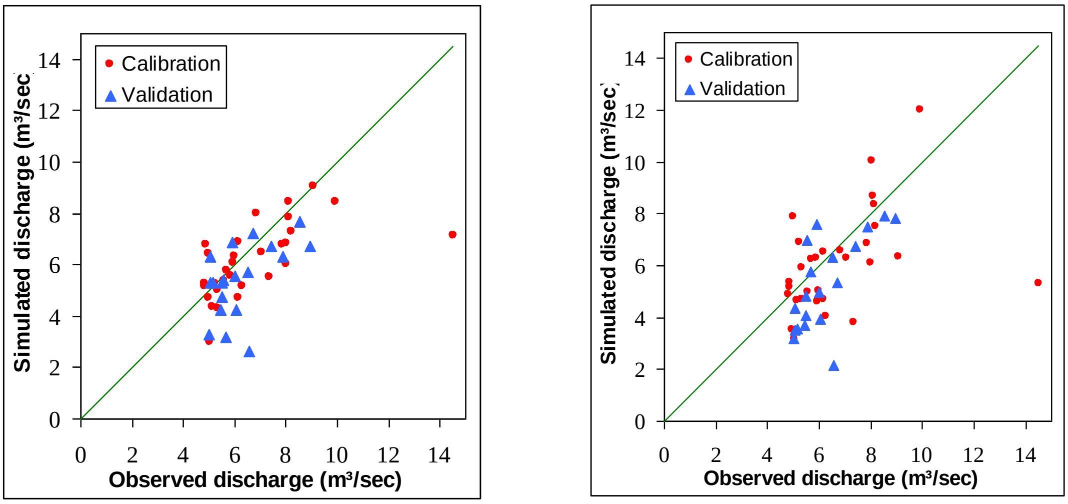
The statistical indices were calculated for both models for the calibration and validation periods (each of 3 years). Better results achieved when RMSE and MAE are minimised to zero & $R^2$and CD and EF are maximised to unity.

Statistics	**NAM**		**MIKE SHE**	
	Calibration	*Validation*	*Calibration*	*Validation*
RMSE	0.1979	0.2030	0.2444	0.2042
MAE	0.3397	0.2960	0.4338	0.2965
CD	1.3058	1.1216	0.8102	1.0877
EF	0.7422	0.7671	0.6070	0.7643
R^2	0.7512	0.7811	0.6912	0.7816

Table 1: Statistical performance indices

➢ Peaks

A set of selective peaks was compared for the calibration and the validation by the two models.
The results are shown in figure 8.



(a) *(b)*

Figure 8: Observed and Simulated Peak flow as a scatter plots: (a) MIKE 11, (b) MIKESHE

Peak Statistics are also calculated in table 2.

Statistics	**NAM**		**MIKE SHE**	
	Calibration	*Validation*	*Calibration*	*Validation*
RMSE	0.2621	0.2444	0.3211	0.2416
CD	1.3519	0.5098	0.8209	0.3935
EF	0.0860	-0.7999	-0.3527	-0.7592
R^2	0.3138	0.2318	0.1545	0.3877

Table 2: Statistical performance indices

➢ Extreme Peak Value Analysis

Figure 9 examine how would the model behave on the long-run to predict the discharge, a set of high peaks were used for that purpose.

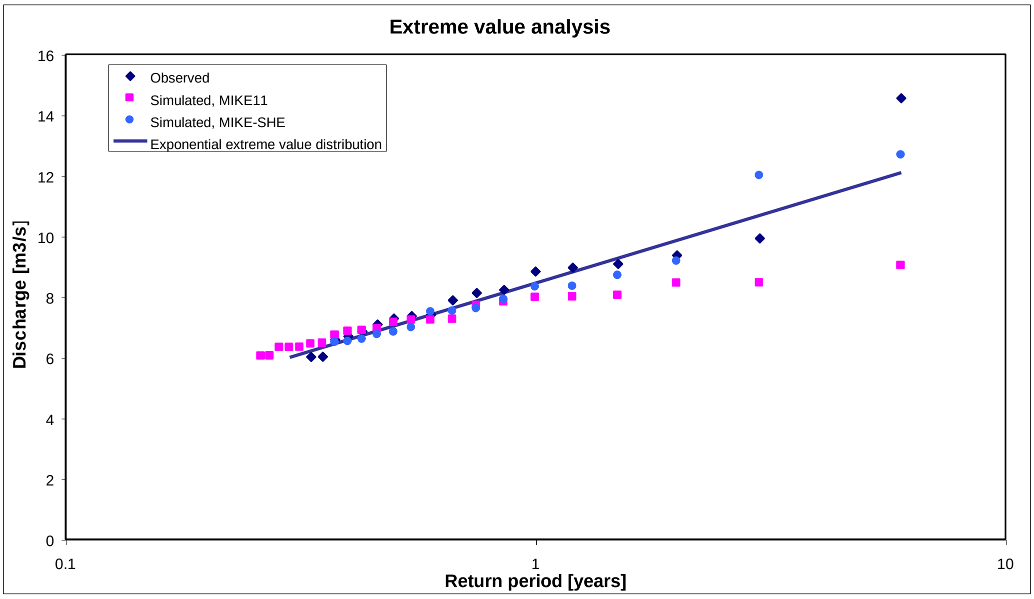


Figure 9: Extreme value analysis

CONCLUSIONS

- The overall results from the goodness-of-fit statistics (Table 1) and the hydrograph outputs together with the scatter plots (Figures 4, 5, 6 & 7) shows that there is no significant difference between the overall behaviour of the two models during the validation period, however NAM performed better than MIKE SHE during the calibration period.

- A closer look at the peak value statistics for the two models (Table 2) and the scatter plots (Figure 8) shows that the same results are obtained as for the whole time series. In the calibration period, NAM behaves better than MIKE SHE. In the validation period, a slight improvement in the NAM output compared with the MIKE SHE results was observed. A tendency to underestimate the values is observed in NAM in both cases (calibration & validation). However, for MIKE SHE this was observed in the validation period only.

- On the basis of an extreme value analysis (Figure 9), the behaviour of both models for flood frequency prediction is additionally examined. The MIKE SHE model performs much better than the NAM model. The largest values are underestimated in NAM and the underestimation increases for larger values, indicating poor performance for extrapolation purposes (wrong tail of the extreme value distribution).

- From these observations, the following conclusions can be drawn. The distributed nature of the MIKE SHE model and the large number of model parameters result in more uncertainty in the description and prediction of individual events, whereas the lumped nature of NAM and the limited number of model input and parameters allows a better overall goodness-of-fit. However, by calibration on the basis of minimisation of overall goodness-of-fit statistics, the NAM model may result in more averaged time series (less variance) compared to the observed series. This in turn may lead to underestimation of peak values. Additional verification of the model by peak value statistics and frequency analysis is therefore needed. Also a less automatic/numerical and more physically based step-wise calibration of model parameters can solve this problem.

- It is worthwhile mentioning that the river routing effect was not taken into consideration while modelling using NAM (for simplicity). However it is not expected that this will have a significant effect on the overall results. Implementing the hydrodynamic model of MIKE 11 (to include the effect of river routing) will flatten the NAM results and may even increase the underestimation of peak values.

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