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Low flow characterization and forecasting in a non-stationary context

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1) Study context

This work is in line with two complementary projects MAJORE and CIPRHES (1) that focus on characterization and forecasting of low flows. The study area focuses on the Rhine-Meuse basin that covers 31 437 km², and includes the French part of the Meuse (7 766 km²) and Moselle (11 437 km²) basins, and those of some left bank tributaries of the river Rhine, including the Ill river.

The French part of the Rhine-Meuse area has faced extreme low flows in recent summers causing difficulties in water resources management (fig. 2). Water managers that monitor hydrological extremes require low flow estimates (MAJORE) and forecasting tools (CIPRHES). This study aims to better understand the processes related to low flows space-time variability. For that purpose, one of the main difficulties is to detect the respective signal of climate variability and human impacts.

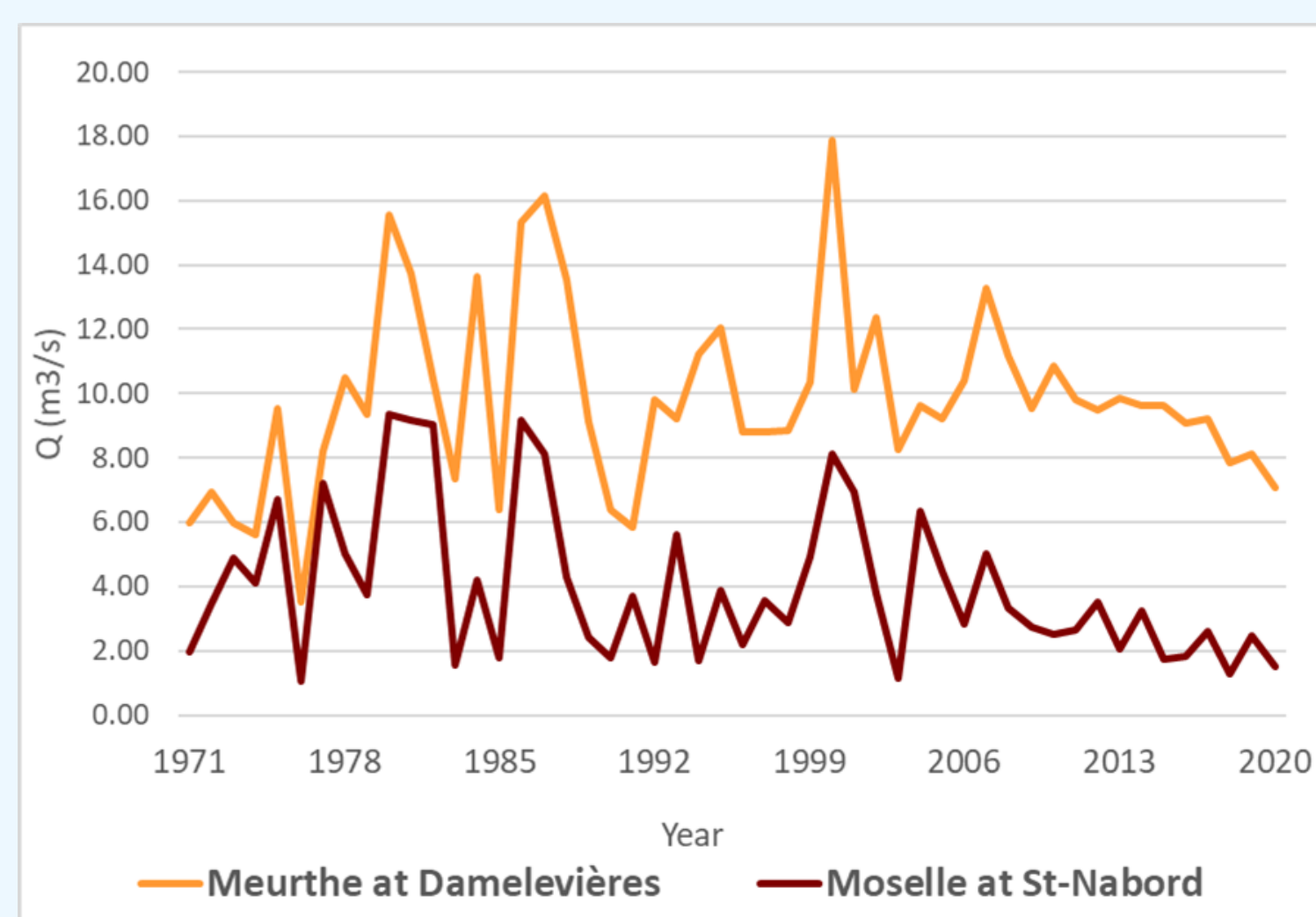


Figure 2: Mean monthly minimum flow

Our research focuses in particular on two different sub-basins (fig. 1). The first one is the Meurthe at Damelevières, having an area of 2 281 km² and which is composed of 14 gauged sub-basins. The Meurthe at Damelevières is influenced by the Vieux-Pré Dam used to release amounts of water for low-flow support. The second sub-basin is the Moselle at Saint-Nabord, which covers an area of 628 km² and is composed of 4 gauged sub-basins. Located in the upstream part of the Moselle basin, the river is subject to a little influence through intake for navigation.

Figure 2 shows mean monthly minimum flows variability, with 1976 and 2003 droughts and successive severe low flows during recent years. For the river Meurthe, there is an artificial change in the low-flow regime since 1986 (Vieux-Pré Dam operating). As many low-flow analyses require data to be stationary there is a need to check this context.

2) A spatial pattern in low flows non-stationarity

Two commonly modified nonparametric tests were used to detect non-stationary series: the modified Mann-Kendall test proposed by Hamed and Rao (1) and the Pettitt's test (2). Mean monthly minimum flows of the period 1971-2019 for 130 stations located in the Rhine-Meuse basin have been tested. Results show that there are 41 non-stationary series (i.e. 32%, for a rejection threshold at 5%), that are mainly located in the Vosges mountains. It appears that the station of the Moselle at Saint-Nabord is not stationary while the station of the Meurthe at Damelevières is stationary.

One issue will be to identify factors explaining the non-stationarity of monthly minimum flows in the Vosges mountains. A semi-distributed model is under development to better understand processes generating low flows and to improve low flow modelling.

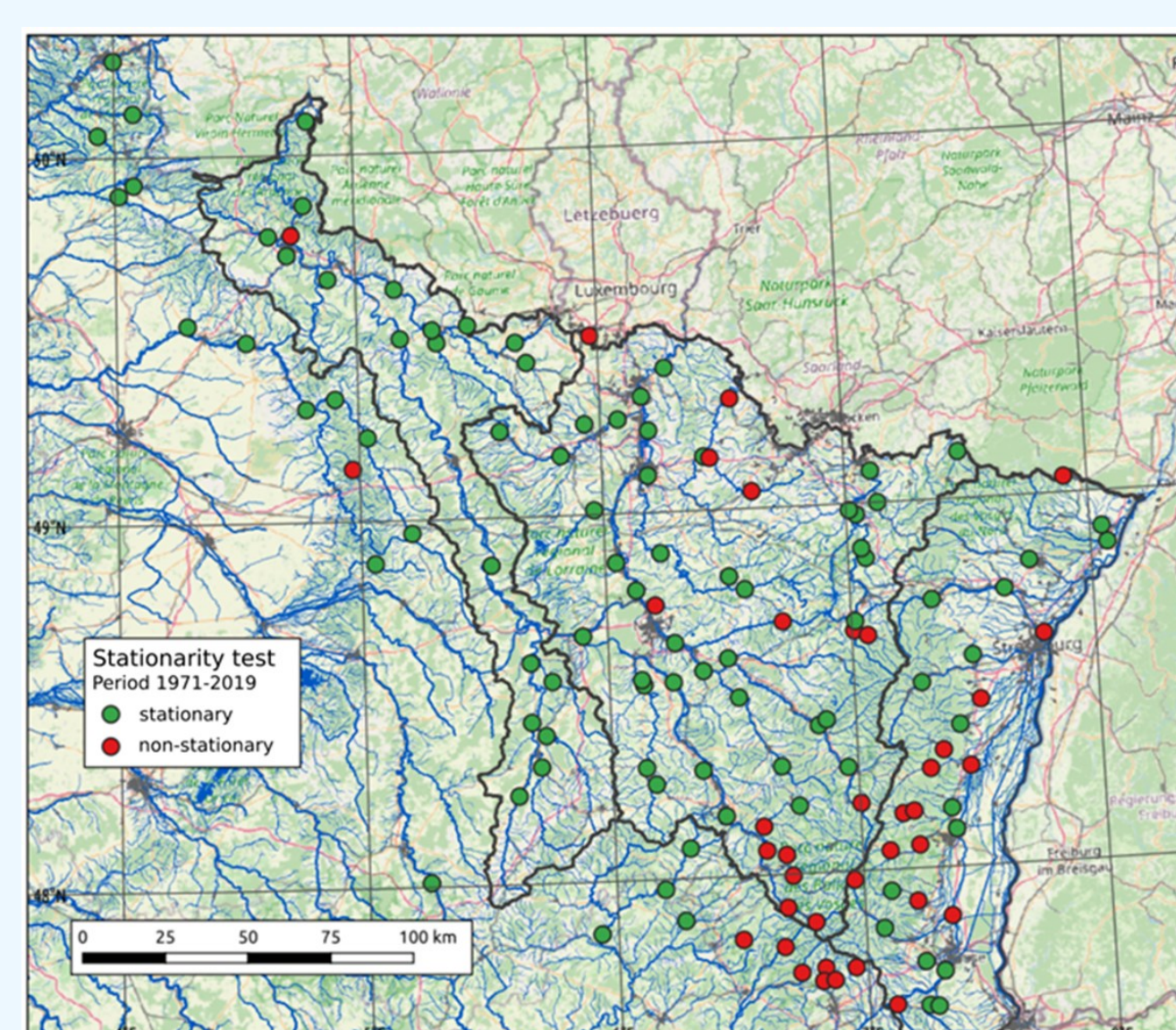


Figure 3: Stationarity of the mean monthly minimum flow 1971-2019

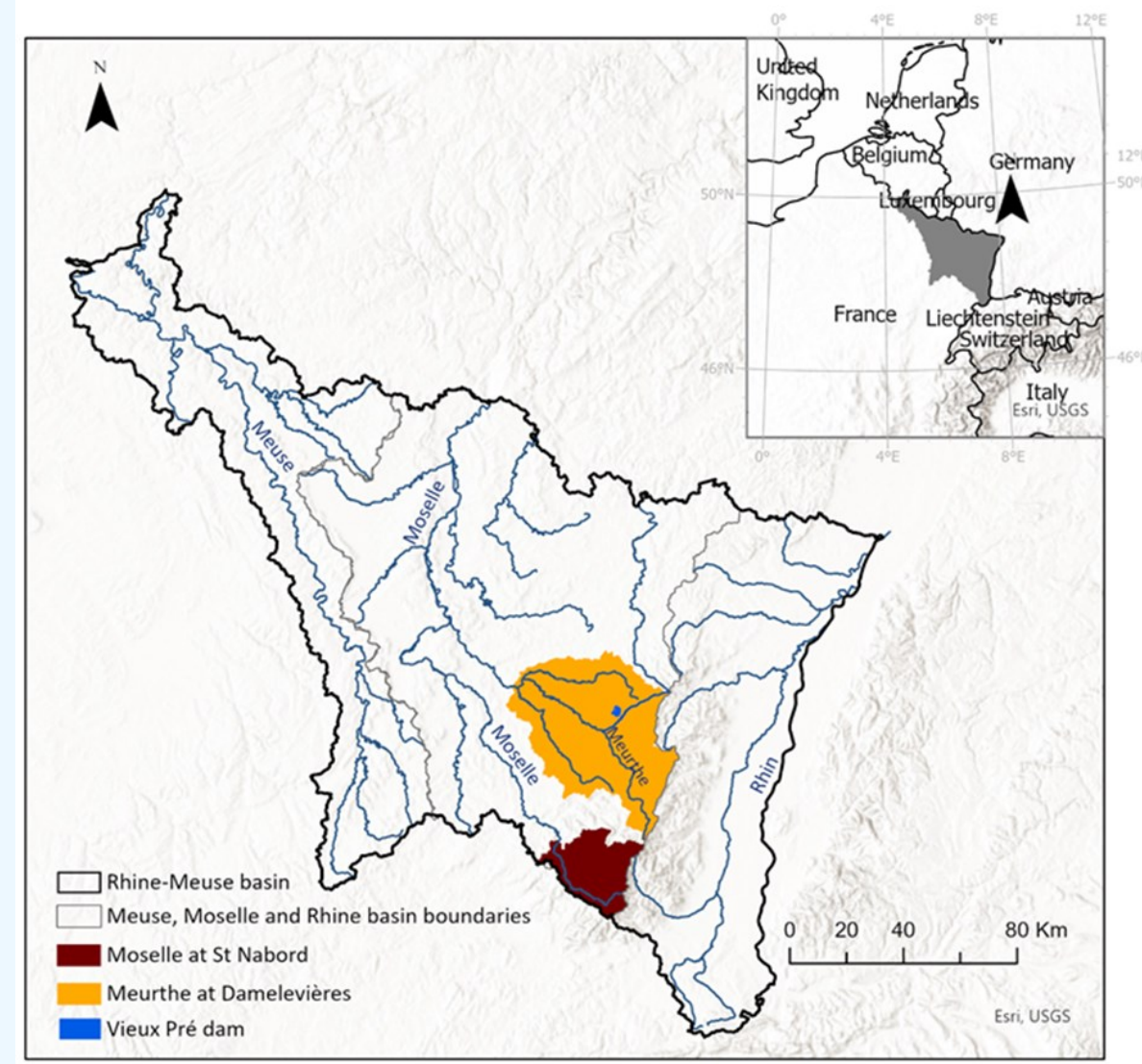


Figure 1: The Rhine-Meuse basin

3) Can a semi-distributed model improve low flow simulations ?

To better understand the low flows processes, the spatial resolution of low flow simulation and forecasting must be improved. We developed a new semi-distributed version of the model PRESAGES (4) that integrates the main anthropogenic influences in the two main sub-basins presented above.

3.1) Method

For the first version of the PRESAGES-SD model, the process follows two steps: applying the lumped version of PRESAGES model (fig. 4) to the sub-basins as well as to the intermediate catchment area (ICA). The equation used is:

$$Q_{basin} = Q_{Sub-basin} + Q_{ICA}$$

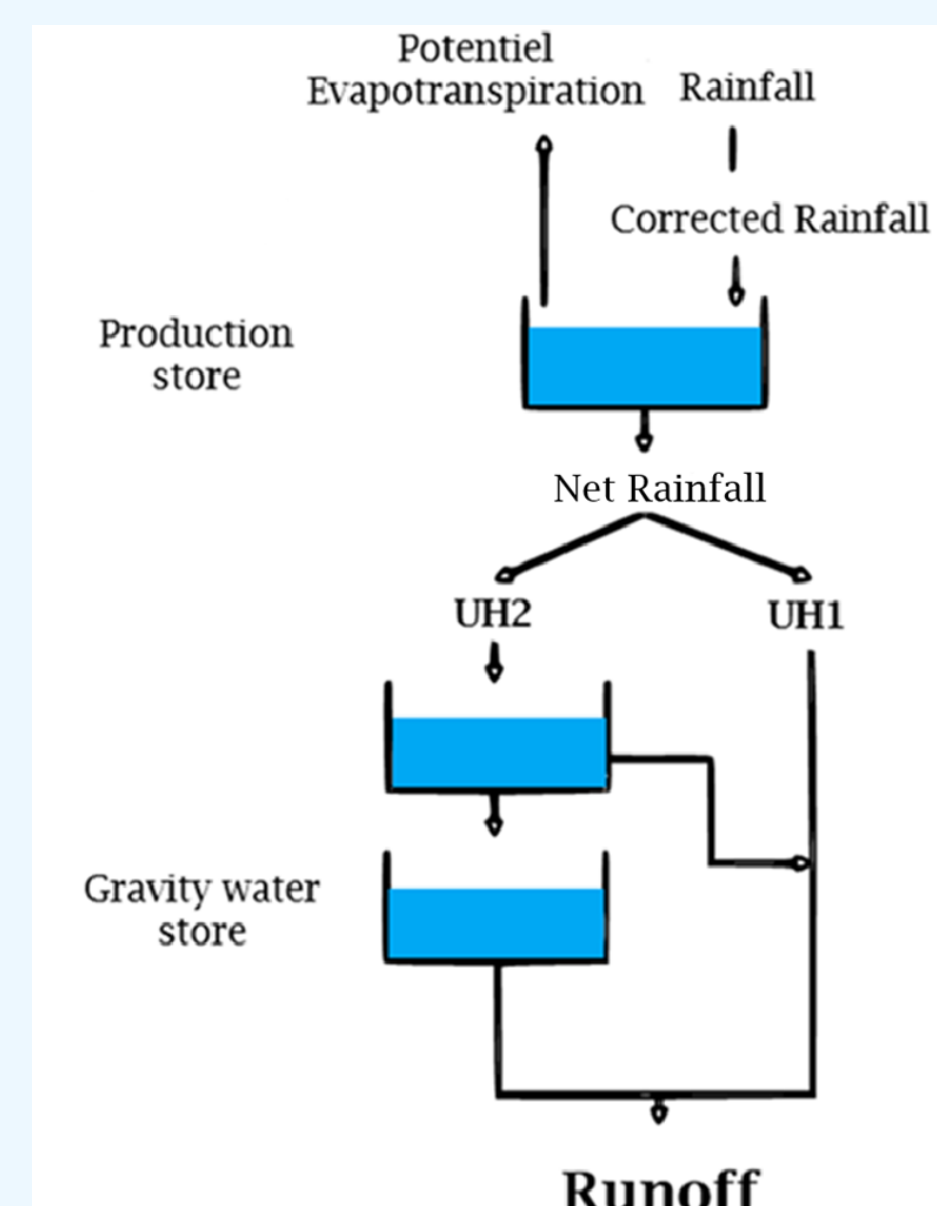


Figure 4: PRESAGES Model

The objective function used to calibrate the model is a combination of the KGE criterion which focuses on low flows.

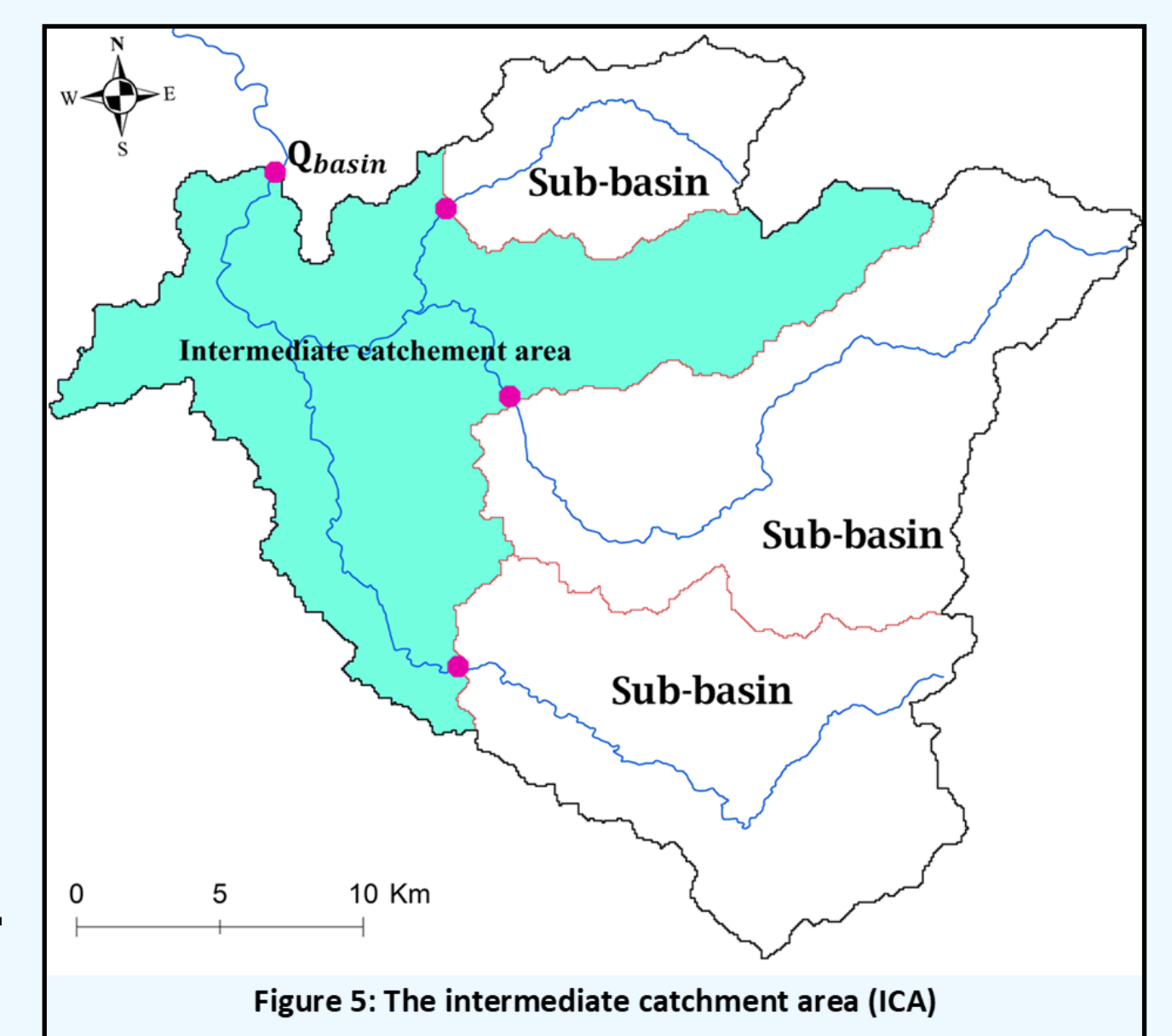


Figure 5: The intermediate catchment area (ICA)

The PRESAGES-SD model is applied to observed and naturalized flow series.

3.2) Results

The PRESAGES-SD model is applied to flows over the recent period (2001- 2020). The period 2001-2010 is used for calibration and the period 2011-2020 for validation and vice versa. The results are preliminary and the PRESAGES-SD model will be improved in the future.

	Split-sample 1: Calibration 2001-2010 / Validation 2011 - 2020			
	PRESAGES Lumped		PRESAGES SD	
	KGE Calibration	KGE Validation	KGE Calibration	KGE Validation
The Moselle at St-Nabord	0.870	0.905	0.870	0.903
The Meurthe at Damelevières	0.839	0.866	0.885	0.898
	Split-sample 2: Calibration 2011-2020 / Validation 2001 - 2010			
	PRESAGES Lumped		PRESAGES SD	
	KGE Calibration	KGE Validation	KGE Calibration	KGE Validation
The Moselle at St-Nabord	0.912	0.872	0.926	0.861
The Meurthe at Damelevières	0.886	0.824	0.902	0.865

Table 1: Performance results

The KGE values presented in table 1 show a small improvement with the SD model in the Meurthe case for the SS1. This efficiency increase with the SD model is also noted for the SS2 in the Meurthe case. The figure 6 shows the result in validation mode of a calibration on naturalized flows.

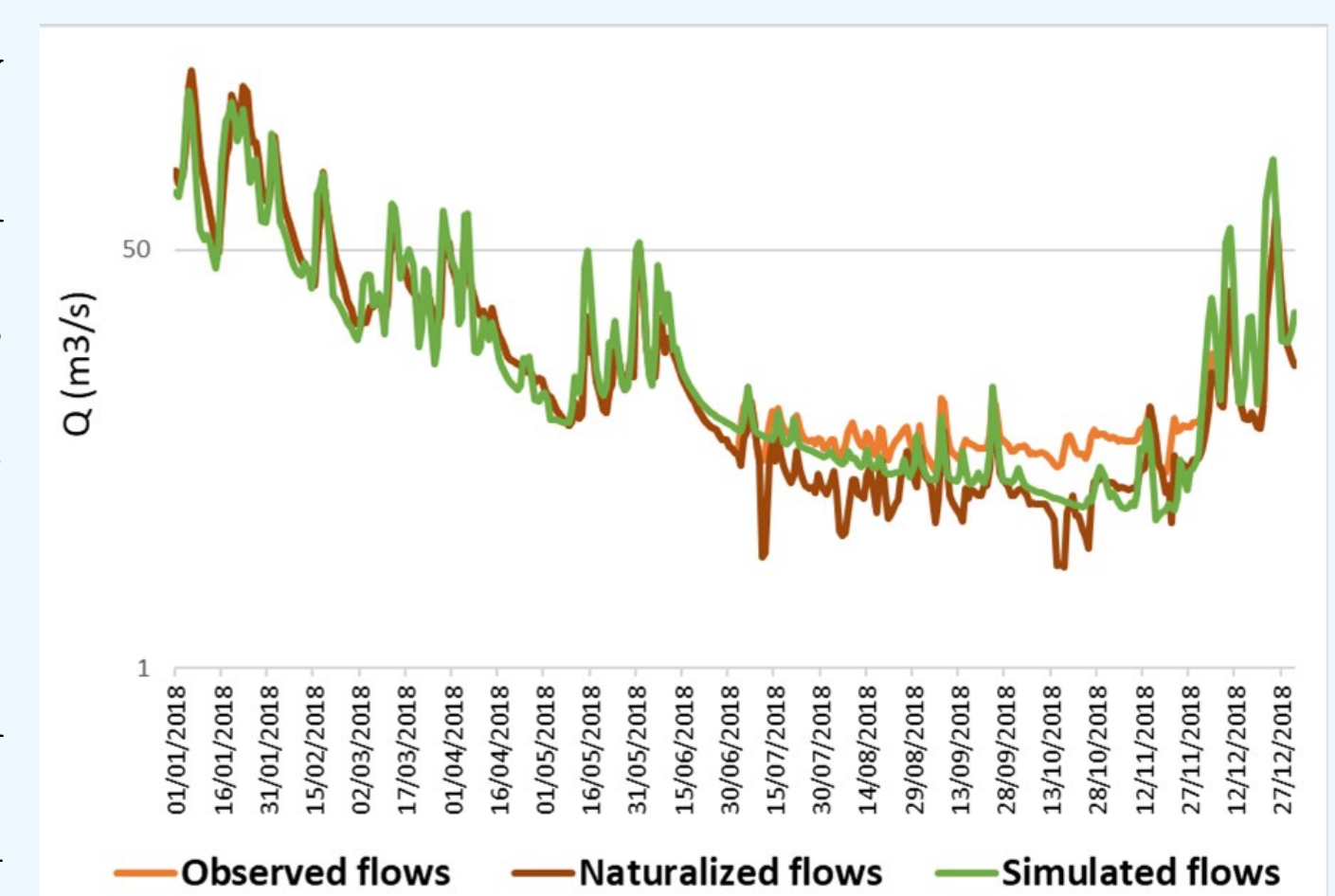


Figure 6: Hydrographs of the Meurthe at Damelevières for 2018

4) Main outcomes

This study rises the challenging question of identifying low flow trends and integrating non-stationarity processes into low flow modelling. The results show a spatial pattern in low flows trends in the French part of the Rhine-Meuse basin. The non-stationarity analysis will be used to identify the reference period for the modeling. For the PRESAGES-SD model, the results are promising. The model is still under development and other approaches will be tested to estimate the contribution of the intermediate catchment area. An extended test on a largest sample of basins will also be conducted.

References:

- 1) Perrin et al., IAHS2022-665, Session 3 - Integrated chain for the hydrometeorological forecasting of low flows and droughts in France. The CIPRHES project.
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