Assessment of future French Meuse low flows through a parsimonious rainfall-runoff modeling approach (with uncertainty)

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This study has been conducted in the framework of the European INTERREG IVB **AMICE** (Adaptation of the Meuse to the Impacts of Climate Evolution) project. The main objective of the study is to estimate the climate-induced evolution of **low flows for the French Meuse river** throughout the 21st century. A wet and a dry climate scenarios are used as inputs of a lumped reservoir-based rainfall-runoff model run on three 30-y periods (1971-2000/2021-2050/2071-2100). The minimum average monthly discharge with a return period of 5 years **(QMNA 1/5)** has been selected as the hydrological impact variable. The latter is currently used in France for establishing the warning and crisis water levels during low flow periods. An attempt of quantifying the rainfall-runoff modelling error is also presented through **the computation of the empirical uncertainty bounds of flow simulations.**

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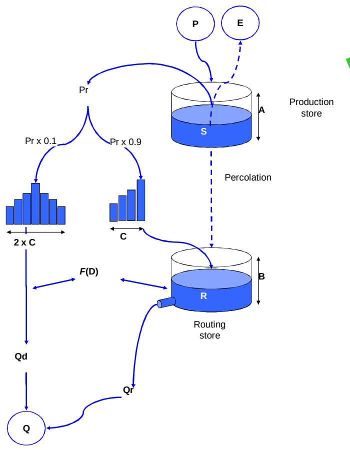
1. Methodology

The GR4J daily continuous rainfall–runoff model (Perrin et al., 2003) has been run on the 1971-2000 period for each of the 7 selected hydrometric stations. **A split-sample test** was applied on the available data in order to check the efficiency of the R-R model and its ability to reproduce the observed values of the minimum average monthly discharge with a return period of 5 years (QMNA 1/5). The efficiency of the R-R model has been estimated through the Nash-Sutcliffe efficiency Coefficient (NSC) **calculated on the log-transformed discharge values**. Results show that the efficiency of the R-R model ranges **from 77 to 90%**. An empirical method of **relative model error computation and correction of the total R-R model error** (Berthier, 2005) is also performed on the basis of simulated hydrographs.



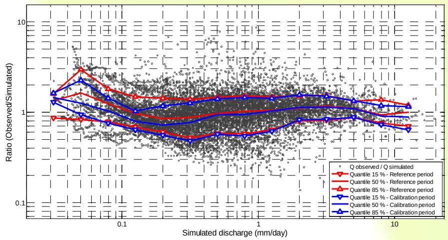
Flowchart of the GR4J rainfall-runoff model (Perrin et al., 2003)

- 4 free parameters have to be calibrated:

A : maximum capacity of the production store (mm)
B : maximum capacity of the routing store (mm)
C : unit hydrograph duration (day)
D : catchment water exchange (mm)

- Input data : daily PET and rainfall values (mm/d)
- Output data : daily discharge series (mm/d)

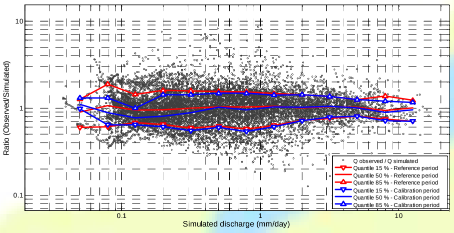
Step 1 : Computation of the relative model errors per class of simulated discharges (The Meuse at Chalaines)



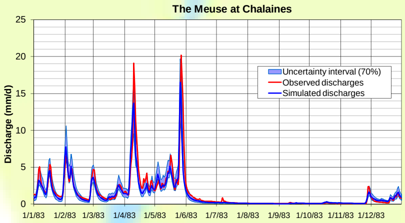
Step 2 : For each class of simulated discharges the bias in flow simulations is removed as follows :

$$Q_{sim_i}^{*} = Q_{sim_i} \cdot \left(\frac{Q_{obs_i}}{Q_{sim_i}} \right)_{0.5} \longleftarrow$$

Median of the relative model errors for a specific class of simulated discharges



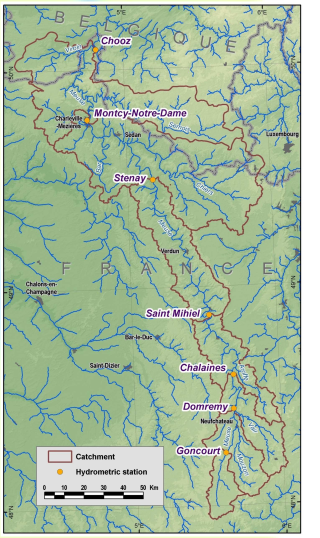
Example of a debiased flow simulation with total uncertainty bounds



Main outcomes

Flow simulations obtained **after step 2** are corrected with the median value of the relative model errors and bounded with percentiles 0.15 and 0.85. The correction method of Berthier (2005) **allows to improve R-R model simulations** with a significant increase of the NSC values. Extreme discharge values obtained after correction, particularly in low flows, provide a better estimation of QMNA 1/5 values (see the hydrological profile of the Meuse river shown below) assumed to be log-normally distributed.

2.Study area and data used



Daily discharge series have been collected through the French « Banque Hydro » web portal, the 7 selected hydrometric stations being monitored by the DREAL Lorraine.

Climate data for the present period (1971-2000) have been extracted from the 0.5° E-OBS gridded dataset (Haylock et al., 2008).

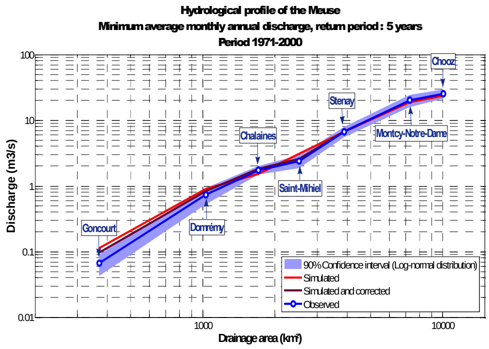
Future seasonal climate trends were provided by Meteo-France (see the companion poster of Commeaux et al.) and applied to present climate series through the delta change approach (see values in the table below).

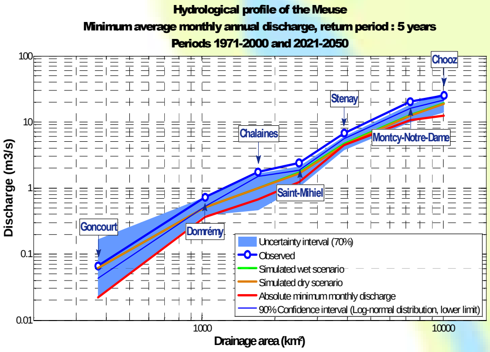
The Potentiel EvapoTranspiration has been calculated through the formulae proposed by Oudin et al. (2005) for the optimization of lumped reservoir-based R-R models.

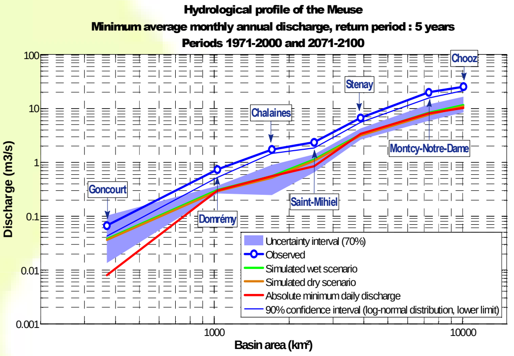
Delta change values for air temperature (℃) and ra infall (%)

Parameter	Period	Scenario	Winter	Spring	Summer	Autumn
Temprature change	2020-2050	Wet	+1.3	+1.6	+2.1	+1.5
		Dry	+1.4	+1.2	+1.7	+1.3
	2070-2100	Wet	+3.4	+3.2	+5.6	+4.2
		Dry	+2.6	+2.7	+4.5	+3.3
Precipitation change	2020-2050	Wet	-7.3%	4.0%	-11.3%	-5.1%
		Dry	-9.2%	-1.0%	-9.1%	-12.8%
	2070-2100	Wet	-8.9%	-10.7%	-28.7%	-22.0%
		Dry	-24.6%	-10.7%	-38.7%	-22.2%

3. Main results







The accuracy of flow simulations is changing according to the hydrometric stations. **In the upstream part of the basin**, despite the correction applied to the daily discharge series, **a strong gap remains between the observed and the simulated values** (see the Meuse at Goncourt). Downstream, from Domrémy to Saint-Mihiel, the correction of daily discharge series provides a better estimation of the QMNA 1/5 observed values. **From the hydrometric station of Stenay to the one of Chooz, flow simulations match closely the observed values** of QMNA 1/5 .

The R-R model failure in the upstream part of the basin **is certainly due both to the size of the basins as well as the lack of deep groundwater reservoirs in this area**. In any cases, the method of correction improving significantly flow simulations, the latter was systematically corrected with the median value of the relative model errors per class of simulated discharges.

Values of the minimum average monthly discharge with a return period of 5 years (QMNA 1/5)

		Hydrometric Station	Goncourt	Domrémy	Chalaines	Saint-Mihiel	Stenay	Montcy	Chooz
		Drainage area (km²)	370	1028	1705	2522	3886	7314	10080
1971-2000	QMNA 1/5 observed values (m3/s)		0,066	0,729	1,75	2,39	6,75	20,1	25,3
	90% Confidence interval	Lower bound (m3/s)	0,043	0,527	1,48	1,86	5,53	15,9	21,4
		Upper bound (m3/s)	0,090	0,931	2,01	2,91	7,96	24,3	29,3
2021-2050	Wet scenario	QMNA 1/5 simulated values (m3/s)	0,061	0,513	0,998	1,71	4,65	12,7	19,1
		Relative change (%)	-8%	-30%	-43%	-28%	-31%	-36%	-25%
	Dry scenario	QMNA 1/5 simulated values (m3/s)	0,062	0,506	0,984	1,65	4,48	12,3	18,8
		Relative change (%)	-7%	-31%	-44%	-31%	-34%	-39%	-26%
	Uncertainty interval (70%)	Lower bound (m3/s)	0,023	0,389	0,462	1,02	3,73	9,87	14,04
		Relative change (%)	-66%	-47%	-74%	-57%	-45%	-51%	-45%
		Upper bound (m3/s)	0,166	0,719	1,63	2,12	5,99	18,22	27,25
		Relative change (%)	151%	-1%	-7%	-11%	-11%	-9%	8%
2071-2100	Wet scenario	QMNA 1/5 simulated values (m3/s)	0,038	0,305	0,547	1,12	3,32	8,28	11,50
		Relative change (%)	-43%	-58%	-69%	-53%	-51%	-59%	-55%
	Dry scenario	QMNA 1/5 simulated values (m3/s)	0,036	0,292	0,519	1,07	3,16	7,73	11,07
		Relative change (%)	-46%	-60%	-70%	-55%	-53%	-61%	-56%
	Uncertainty interval (70%)	Lower bound (m3/s)	0,013	0,262	0,244	0,660	2,63	5,98	8,50
		Relative change (%)	-80%	-64%	-86%	-72%	-61%	-70%	-66%
		Upper bound (m3/s)	0,101	0,371	0,895	1,40	4,28	11,9	16,7
		Relative change (%)	53%	-49%	-49%	-42%	-37%	-41%	-34%

Whatever is the future time slice considered (2021-2050 or 2071-2100), the sensitivity of the simulated hydrological response of the French Meuse river to the type of climate scenarios (wet or dry) is pretty weak.

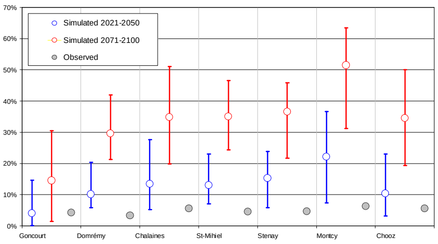
The main difference between the two climate scenarios is especially observed during winter for rainfall totals, but low flows seem to be relatively few influenced by this difference. Therefore the projected trends for QMNA 1/5 **can be analyzed through only one climate scenario**.

In the upper part of the French Meuse river basin, the total R-R model uncertainty is so large that it is not possible to predict the evolution of the QMNA 1/5. From Chalaines to Montcy, the uncertainty bounds of model simulations no longer overlapped the observed hydrological profile of the Meuse river, **the prediction of what might happen due to climate change being more detectable for those stations**. The decrease of the QMNA 1/5 is quite strong and ranges from -28% to -44%.

At Chooz, the differences between the present and the future hydrological profiles are much more reduced according to the climate scenario, lying between -26% to -25%, this value corresponding to the lower bound of the 90 % statistical confidence interval fitted on the QMNA 1/5 present values (see also the Meuse at Domrémy).

Last, for the hydrometric stations of Stenay and Montcy, **the predicted value for the QMNA 1/5 is close to the absolute minimum value of the present minimum monthly discharges**.

Percentage of days below the minimum average monthly discharge with a return period of 5 years (uncertainty interval of 70% included)



For the selected hydrometric stations, the observed minimum monthly discharges are below the QMNA 1/5 values during **5 % of the time for the present climate** (period 1971-2000).

In the future, the minimum monthly discharges might be below this critical threshold **from 6 to 22 % of the time for the 2021-2050 period** and **from 15 to 50% of the time for the 2071-2100 period**.

For the end of the 21st century, during low flows, the simulated discharge values being out of the simulated range of values for the present climate, the median of relative model errors per class of simulated discharges was supposed to be similar to the one calculated on the closest class of simulated discharges for the present climate.

For the end of the 21st century, as expected, the discrepancy between the present and the future hydrological profiles is much more important. Goncourt is the only hydrometric station where the change affecting the QMNA 1/5 may be still unpredictable due to a strong R-R modeling uncertainty.

The predicted values of the QMNA 1/5 are very low since, except for the Meuse at Goncourt, **they are all comparable to the absolute minimum daily value of the present daily discharge series**…

4. Conclusions and outlook

Significance of predictions concerning the GHG-induced climate change impact on basin hydrology is investigated within the context of a case study for the French Meuse river basin. The study was focusing on the low flows and especially the minimum average monthly discharge with a return period of 5 years (QMNA 1/5). For this purpose a parsimonious reservoir-based hydrological model has been used and a first attempt to quantify the empirical uncertainty of prediction has been carried out.

It has been found that the evolution of the QMNA 1/5 due to GHG-induced climate change **is not always predictable with a R-R model**, **depending on the size of the basin and the future time slice considered**. In response to the climate forcing, the evolution in **low flows is much more significant during the second half of the century.** This trend raises the question **of adaptation strategies that needs to be developed for improving the water management in the Meuse river basin** during the **summer season** which appears **very likely** as **a hot spot** of the annual hydrological cycle in the future.

Future works will try to test the sensitivity of the rainfall-runoff model parameters to the climate variability and to look for alternative methods to R-R model for predicting minimum average monthly discharge with a return period of 5 years.

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