Uncertainty in climate change impacts on low flows

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Extended abstract

Water management in Western Europe often focuses on water levels and discharges during floods. Reasons are obvious, since floods determine maximum water levels and therefore safety against inundation. The focus on floods is partly forced by the fact that in future higher and more frequent floods are expected as a result of climate changes. However, climate changes are also expected to lead to drier summers in Western Europe. Consequently, low flows in rivers become more frequent. Low flows, occurring during dry periods, may result in several types of problems to society, e.g. lack of water for drinking water supply, irrigation, industrial use and power production, hindrance to navigation and deterioration of water quality. Facing these problems, it is crucial for low flow management that information about the impacts of climate change on low flows and the uncertainties herein becomes available. The objective of this study is therefore to assess the uncertainty in impacts of climate change on low flows in the river Meuse in North-western Europe.

Changes in climate variables relevant for low flow, in particular precipitation and temperature, are assessed using observed station data and results from Regional Climate Models (RCMs) for different greenhouse gas emission scenarios. The RCM results have been obtained from the EU-project PRUDENCE in which different RCMs and scenarios have been compared. The uncertainty in the climate change projections of climate variables is assumed to be mainly the result of different emission scenarios, sampling errors, different boundary forcing by Global Climate Models (GCMs) and different RCMs. This uncertainty is summarised by probability distributions for relevant statistics of the selected climate variables. In the uncertainty analysis, statistics are randomly drawn from these probability distributions and used to transform current and changed climate series.

The conceptual hydrological model HBV is used to simulate hydrological behaviour in general and low flows in particular for current and changed climate conditions. The calibration of HBV for current climate conditions is done using a fuzzy measure as objective function. This fuzzy measure combines several objective functions for low flow simulation (e.g. modelling error in discharge deficit) and simulation of the discharge regime (e.g. Nash Sutcliffe coefficient). Fuzzy logic allows the handling of the concept of a partial truth value between completely truth and completely false. Validation of the model is done for a period different from the calibration period. The uncertainty in the hydrological model is represented by the uncertainty in its parameters. Through consideration of this parametric uncertainty, model structural and scale related uncertainties are not explicitly taken into account. However, these are assumed to be at least partly covered by the parametric uncertainty. Similarly as for the climate variables, in the uncertainty analysis, parameters are randomly drawn from probability distributions of these parameters.

The different uncertainty sources (emission scenarios, sampling, boundary conditions, RCMs, HBV parameters) are propagated through the HBV model using Monte Carlo analysis. This finally results in a probability distribution of low flows for current and changed climate conditions. This enables an assessment of the significance of changes in low flow conditions with climate change by comparing changes and uncertainties. Low flows are described by the average annual discharge deficit. The discharge deficit is the cumulative shortage of water with respect to a certain threshold important for river functions like shipping, agriculture and drinking water supply.

The RCM results show an annual average increase in temperature of 4.0 ºC for climate change conditions (2071-2100) varying between 3.3 ºC in DJF (December-January-February) and 5.1 ºC in JJA (June-July-August). Precipitation decreases slightly by 2.5 % on an annual basis varying between +24 % in DJF and -35 % in JJA. Uncertainties with climate change (expressed as standard deviation) vary between 1.0 ºC in DJF and 1.7 ºC in JJA for temperature and 8.9 % in MAM (March-April-May) and 13.4 % in JJA for precipitation. Uncertainties in these climate variables for current conditions (1971-2000) are somewhat (30-50 %) smaller, because emission scenario uncertainties do not apply. All uncertainties in climate variables are assumed to stem from a normal distribution.

Results of the HBV model calibration show good performance for low flow as well as for average and high flow simulation using the fuzzy measure. Nash-Sutcliffe coefficients for different sub-basins of the Meuse are between 0.80 and 0.90 and over 0.90 for the complete basin. Differences between observed and simulated discharge deficits are less than 5 %. Validation results are slightly better than calibration results due to the better data quality for the validation period. Uncertainties in the HBV parameters (expressed as standard deviation) are assumed to be of the same order of magnitude as the uncertainty in precipitation under current climate conditions and stem from an uniform distribution.

Combining RCM and HBV results enables an assessment of climate change impacts on low flows and related uncertainties. Climate change results in an increase of the average annual discharge deficit of about 2.6 10^8 m^3 or 35 %. This increase is caused by both a decrease of precipitation in particular in JJA and in SON (September-October-November) and an increase of temperature and related evapotranspiration all year round. The uncertainty in this impact (expressed as standard deviation) is about 0.9 10^8 m^3 as a result of uncertainties in climate change, 0.2 10^8 m^3 as a result of uncertainties in HBV parameters and 1.0 10^8 m^3 as a result of both. For current climate conditions, these uncertainties are about 0.5 10^8 m^3, 0.2 10^8 m^3 and 0.6 10^8 m^3 respectively. Relative uncertainties of discharge regime variables (with respect to their means) like the standard deviation of daily discharges have a similar magnitude (5-15 %).

It thus can be concluded that the impacts of climate change on low flows are considerable resulting in an increase of water shortages in the Meuse basin during low flow periods. Uncertainties in these impacts are large, although not disguising the climate change signal. These uncertainties are mainly the result of uncertainties in climate variables and to a smaller extent due to uncertainties related to the hydrological model. It is expected that uncertainties in phenomena occurring at low frequencies with climate change will be considerably larger than the uncertainties in relatively frequent-occurring phenomena investigated here (discharge deficit, daily variability).