Application of a weather generator to simulate extreme river discharges in the Rhine and Meuse basins

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Abstract

A weather generator has been developed to simulate long-duration sequences (1000 years or more) of daily discharges using a hydrological/hydraulic model. Resulting extreme value distributions of 10-day rainfall amounts and daily river discharges are discussed.

Introduction

The traditional method for the estimation of the design discharge is based on the extrapolation of the distribution of recorded annual discharge maxima to a mean return period of 1250 years. Disadvantages of this method are that strong extrapolation is required, and that discharge records are potentially inhomogeneous. Furthermore, considering annual discharge maxima gives no insight in the shape and duration of the flood peaks. Since the mid 1990s a new methodology is under development, which aims at the simulation of long-duration discharge sequences. Besides a hydrological model (HBV) and a hydraulic model (SOBEK), also a stochastic weather generator is involved to synthetically generate realistic long daily sequences of rainfall and temperature for the river basin.

The weather generator

Rainfall and temperature at different locations in the drainage area are simultaneously simulated by 'nearest-neighbour' resampling. A major advantage of this resampling method is that both the spatial association of daily rainfall over the drainage basin and the dependence between daily rainfall and temperature are preserved, without making assumptions about the underlying joint distributions. To incorporate autocorrelation, one first searches the days in the historical record (here 10), whose characteristics are most similar to those of the previously simulated day, referred to as 'nearest neighbours'. One of these nearest neighbours is then randomly selected using a decreasing kernel and the observed values for the day subsequent to that nearest neighbour are adopted as the simulated values for the next day. The search for nearest neighbours of the previously simulated day is based on quantities like the basin-average rainfall and temperature for that day, the rainfall total of the preceding four days and the fraction of the basin for which the daily rainfall exceeds the wet-day threshold of 0.3 mm. The effect of seasonal variation is reduced by restricting the search for nearest neighbours to days within a moving window of 61 days, centred on the calendar day of interest. The variables being simulated do not necessarily play a role in the selection of nearest neighbours (e.g. areal rainfall for a sub-catchment) but are supposed to be closely related to those variables influencing the selection. More details about nearest-neighbour resampling can be found in Buishand and Brandsma (2001).

Results

Figure 1 compares the distribution of the 10-day winter maxima of basin-average rainfall for four 3000-year simulations for the Meuse basin with the corresponding distribution of the historical winter maxima (October through March) for the period 1961-1998. These extremes are considered because large river discharges are often caused by large multi-day rainfall amounts in winter. The figure shows that the weather generator is capable of reproducing the distribution of the 10-day rainfall extremes well. Furthermore, the historical maximum 10-day rainfall amounts is largely exceeded in the simulations. It is expected that this leads to higher flows than those observed. Figure 2 displays the distribution of annual maxima of daily discharge for the Rhine at Lobith from three 50-year simulations, to which Gumbel distributions are fitted. Large differences between the simulations are found if these distributions are extrapolated to return periods in the order of 1000 years. Figure 3 shows the same for three simulations of 1000 years, except that three-parameter GEV distributions are fitted to the data. These show a considerably smaller spread for long return periods.

Conclusions

The weather generator reproduces observed properties of extreme rainfall well and is also capable of simulating more extreme events than have been observed in the past. Large extrapolation of distributions fitted to observed discharge maxima are very uncertain. The use of a weather generator with a hydraulic/hydrological model can help reduce the uncertainty in the estimated extreme flows for long return periods.

References

Buishand, T.A., Brandsma, T. (2001): Multi-site simulation of daily precipitation and temperature in the Rhine basin by nearest-neighbor resampling. Water Resour. Res., 37: 2761-2776.

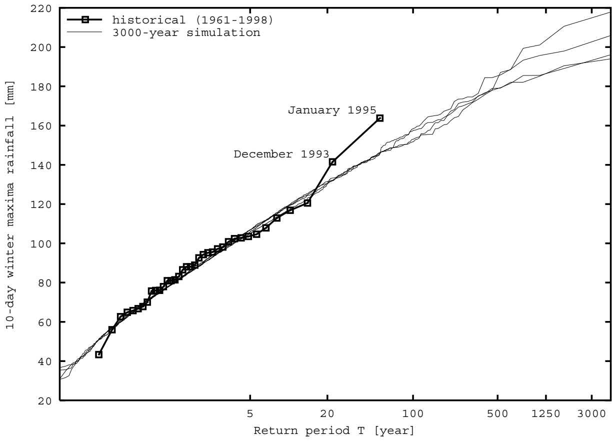

Figure 1. Gumbel plot of winter maxima (historical and simulated) 10-day basin-average rainfall for the Meuse.

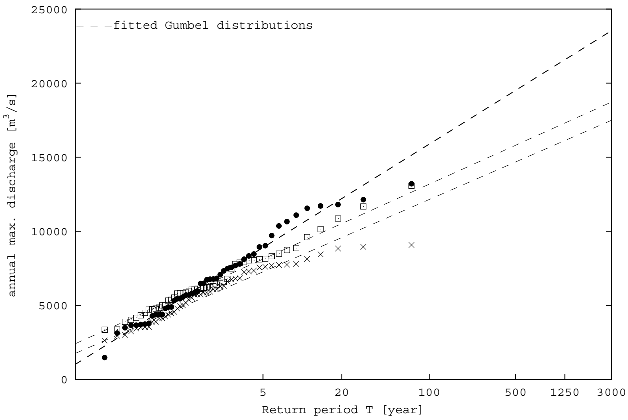

Figure 2. Gumbel plot of annual maxima of daily discharge of the Rhine at Lobith from three 50-year simulations.

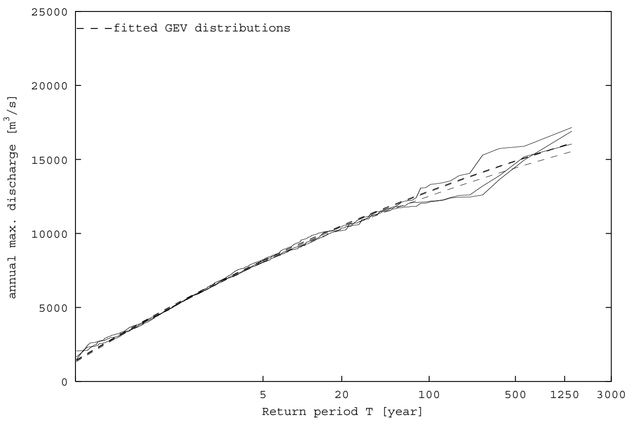

Figure 3. Gumbel plot of annual maxima of daily discharge of the Rhine at Lobith from three 1000-year simulations.