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Assessment of extreme flood characteristics based on a dynamic-stochastic model of runoff generation and the probable maximum discharge

L.S. Kuchment and A.N. Gelfan

Water Problems Institute of the Russian Academy of Sciences, Moscow, Russia

Correspondence
A.N. Gelfan, Water Problems Institute of Russian Academy of Science, 3 Gubkina, Moscow 119333, Russia
E-mail: hydrowpi@aqua.laser.ru

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Abstract

A dynamic-stochastic model of flood generation consisting of a distributed physically based model of snowmelt runoff genesis and a stochastic weather generator has been used for the assessment of extreme flood risk. Coupling this model with Monte-Carlo simulations of meteorological series allows one to calculate long series of runoff hydrographs and the exceedance probabilities of flood peak discharges and volumes. The implementation of such a dynamic-stochastic methodology may provide an improvement in extreme flood risk assessment in comparison with the traditional flood frequency analysis of the hydrological series. However, for very rare events, the uncertainty in estimating flood risk may increase significantly. To decrease this uncertainty, it has been suggested to combine the peak discharge series obtained by dynamic-stochastic simulations with the probable maximum discharge (PMD) calculated through the physically based model of snowmelt runoff generation. This combination is achieved by fitting the estimated exceedance probabilities of simulated peak discharges by the Johnson distribution with the PMD as the parameter. The sensitivity of the fitted Johnson distribution to the errors of the PMD estimations is analysed. A case study in Russia is carried out for the Vyatka River basin (the catchment area is 124 000 km^2).

Introduction

The planning and design of water resources systems as well as flood-plain management are dependent on reliable estimates of flood frequency. Increasing demands for the acceptable economic and environmental risk have necessitated improving the reliability of existing methods of estimation of large floods, especially extreme floods of very low exceedance probabilities.

In hydrologic practice, there are two main approaches to the estimation of extreme flood characteristics. The first one is based on the acquisition of data of flood peak discharges, computation of observed probabilities of occurrence, fitting of the appropriate probability distribution to the observed probabilities and, finally, estimation of flood quantiles of the desired probabilities. This approach yields reliable estimates of flood peak discharges if the recurrence intervals of these discharges do not significantly exceed the length of the measured peak discharge series. However, the fundamental weakness of this approach to estimating floods of a return period that is much longer than the period of flood observations is widely known (e.g. Swain *et al.*, 1998; Singh and Strupczewsky, 2002) and arises from the facts that the recorded data of flood extremes are scarce and statistically nonhomogeneous. These data deficiencies result in the unreliability of estimations of the desired extreme floods. Additionally, for the solution of many hydrological and environmental problems, it is important to know not only the maximum flood peak discharges but also the maximum flood hydrographs.

The second approach is based on an assumption that there are some physical limits of rainfall or snowmelt rate for each region and for each season and these values can be utilized for the calculation of the hydrograph of the probable maximum flood (PMF), i.e. the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are physically possible in a particular drainage area. The PMF is of importance in the design of large dams. For projects with less responsibility, the design floods are typically used from 40% to 60% of the PMF. In this approach, the probability of the desired possible maximum discharge is not estimated, which creates