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Hydrological modeling of spatial long-term forecasting of maximum water discharge of spring flood using the example of the rivers of the Baltic region

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1. Introduction

Hydrological modeling of river flows is a priority in the field of hydrological calculations and forecasts (World Meteorological Organization, 1994). The rivers of the Baltic region belong to the flat type of predominantly snow feeding and are characterized by the formation of maximum water discharge during the spring flood.

The article is concerned with analysis of the processes of formation of spring floods of lowland rivers and the development of a methodological framework for spatial long-term forecasting of the maximum water discharge of spring floods for more reliable regulation of the reservoirs water regime and the implementation of protective measures during the passage of the highest floods (for example, the rivers of the Zapadnaya Dvina/Daugava basin).

Hydrological modeling in order to predict runoff is usually carried out for rivers that have systematic observations of river runoff. The maximum water discharges are usually formed most quickly on small rivers, on which there are no data on water runoff measurements.

Unlike runoff depths, maximum water discharge during spring flood cannot be generalized for different rivers of the territory, since they comply with reduction under the influence of changes in river catchment areas and other morphometric characteristics of the basins.

The proposed hydrological model solves the problem of predicting the maximum ordinate of spring floods with a long lead-time and in real time for rivers with any dimensions of catchment areas and under different physiographic conditions for the formation of river runoff (Gopchenko et al., 2005).

Also an important issue in the context of modern climate fluctuations and the presence, in connection with this, of temporary decreasing trends in maximum water discharge of spring floods of lowland rivers, is the assessment of their values (long-term average and various exceedance probability) for a long period in the future. For the rivers of the Baltic region, there are current trends shifting the dates of maximum discharges from melting of snow to earlier dates (Blöschl et al., 2017).

2. Research methodology

The basis of the hydrological model of the forecast scheme are the regional dependences of the maximum water discharge on the values of the maximum water supply in the snow on the catchment presented as their modular coefficients $k_m = f(k_S)$ (Gopchenko et al., 2005, Shakirzanova et al., 2017; Dokus et al., 2018).

Taking into account the different character of development of spring flood processes in different years, the predicted dependencies are differentiated into three categories of flood heights – high, medium and low.

For such a separation of the available time series by maximum runoff, a discriminant analysis apparatus was used, the predictor vector of which included the main hydrometeorological flood factors: maximum water supply in snow, autumn or spring moistening of the soil, depth of freezing, characteristics of thaws in winter and snowmelt processes in spring.

The main factors forming the maximum river runoff were selected within the allocated regions, homogeneous according to the conditions of spring flood formation, using the methods of factor and cluster analysis (Gopchenko et al., 2005).

The forecast of maximum spring flood discharges is issued as of 1 March in each year, and is also updated on 15 March and the date of the maximum snow storage on the catchment. The forecast is issued in real time using an automated software package developed by the authors (Gopchenko et al., 2006, Shatokhin et al., 2018). The lead-time for forecasts for different dates of their release averages 50 to 30 days or less.

The spatial forecast is presented in the form of annually compiled distribution maps of the maximum modular coefficients across the territory k_m. The transition to the predicted values of the maximum runoff modules q_m is carried out when determining the average long-term maximum runoff modules of the spring flood q_0.

If there are series of observations, the average multi-year maximum modules are determined by statistical methods. If they are absent, a modern operator model for the formation of the maximum river runoff is proposed for calculation q_0 (Ovcharuk et al., 2018). This model allows you to calculate and generalize all the initial parameters of the calculation scheme, including those obtained from observational data and those that are not measured by the hydrometeorological network, but are calculated numerically by the model.

In addition, the operator model allows to assess possible changes in the maximum runoff of spring floods due to future climate changes by introducing “climate corrections” calculated according to the models and scenarios of the Intergovernmental Panel on Climate Change (IPCC, http://ipcc-data.org).

The hydrological model of spatial long-term forecasting also allows to determine the forecast probabilities of the maximum water discharge of spring flood in a multi-year period. As a base, a three-parameter gamma distribution was used (with the coefficients of variation of the maximum water discharge C_v specified as a map and the fixed ratio (C_s / C_v) = 2.5). The forecast probabilities are summarized across the territory based on annually compiled maps of water supply.

A hydrological model for spatial long-term forecasts of maximum spring floods has been implemented and estimated using data from 13 rivers of the Zapadnaya Dvina/Daugava river basin with a hydrometeorological observation period of 21-44 years.

3. Methodology evaluation

Evaluation of the effectiveness of the proposed hydrological model for predicting the maximum water discharge of spring flood was carried out in two stages. At the first stage, according to the Fisher criterion, the reliability of the separation in the discriminant analysis of the totality of cases (years) into flood groups is established – high, medium and low. At the second, the model is evaluated according to the quality criterion S/σ (where S – the mean square error of the verification forecasts, σ – the acceptable error) and availability of acceptable error of verified forecasts (statistical correctness of forecast) – $P\%$. For the rivers of the territory under consideration, a criterion for the quality of the forecast methodology was obtained in different calculation options for the discriminant function with a different set of flood factors in the predictor vector. At the same time, the values of the quality criterion S/σ vary from 0.55 to 0.76, and the availability of acceptable error is from 81 to 66%, respectively.

A decrease in the quality of the methodology for forecasting the maximum water discharge of spring flood is observed in those areas where, by the main date of the forecast (1 March), maximum water supply in the snow have not yet formed and their subsequent accumulation is observed. In this case, it is recommended to issue clarifying forecasts on 15 March, and then necessarily on the date of the maximum water supply in the snow.

The acceptable forecast error in the presence of series of observations of the maximum water discharge is determined by the probable deviation of the value from the average long-term value, and if they are absent, it is estimated from its dependence on the catchment area proposed in the work.

4. Conclusions

The hydrological model presented in the work is recommended as a methodological basis for the compilation of spatial long-term forecasts of the maximum water discharge in spring floods of lowland rivers. The forecast scheme proposed in this work can be used directly for long-term forecasting of the maximum water discharge of spring flood on the rivers of the Zapadnaya Dvina/Daugava basin, not only in individual points where there are long-term series of observations, but also in general for rivers of the territory with different catchment areas and in different physical and geographical conditions for the formation of river runoff.

The model allows to evaluate the possible changes in the maximum runoff of the spring flood of the rivers in connection with future climate changes by introducing "climate corrections" to their average long-term values.

A forecast is presented in the form of two maps – modular coefficients of maximum water discharge and their forecast probabilities over a multi-year period.

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