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Hydrological modeling of floods characteristics of the Northern Dvina river near the city of Velikiy Ustyug

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Northern Dvina River reach from Velikiy Ustyug city to Kotlas city is one of the most problematic ice jam flooding areas in the European Russia. During all its history from 13th century the ancient Russian city of Velikiy Ustyug was flooded repeatedly. The last large floods were observed here in 1998 and in 2016, when more than half of the city and nearby territories were inundated.
STREAM_2D hydrodynamic model (authors V. Belikov et al.), which is based on the numerical solution of two-dimensional Saint-Venant equations on a hybrid curvilinear quadrangular and rectangular meshes was applied for the simulations of flooding. The part of the Northern Dvina valley from Velikiy Ustyug to Kotlas, including the confluence of the Sukhona and Yug rivers, with a total length of about 90 km, was included into the computational domain. Detailed field data about water regime of the Northern Dvina river, bathymetry of the channels and topography of the floodplains was collected for model developing. As input into hydrodynamic model water discharges of the Sukhona and Ug rivers, defined by the two ways: on the base of data of gauge stations and on the base of output discharges from river runoff formation model ECOMAG (author Yu. Motovilov) were used. Second approach gives opportunity to use the complex of models in the forecasting mode. For models calibration and validation different scenarios for high flood periods and ice jamming, including the data on the most catastrophic floods in 1998 and 2016 were considered. Modeling has shown good correspondence between observed and simulated water levels for gauging stations river Sukhona - city Velikiy Ustyug, Northern Dvina – gauge Medvedki, and simulated flooding areas with flooding zones, received from satellite images.
Modeling of 1 and 5% exceedance probability floods was performed, the flood risk and efficiency of large-scale levees was analyzed. The simulations have showed that the water levels that formed by flood runoff of 1% recurrence may exceed the dry-season levels by 6–7 m. In this case, more than 90% of the river valleys can be inundated, water depths in the flooded part of the city Velikiy Ustyug, situated on a high floodplain, are about 0.5 - 1 m. In case of the ice jamming, the maximum levels can increase by another 2–3 m. Economic and environmental damages reach the maximum at water levels at Velikiy Ustyug more than 880 cm above gauge datum. Such levels are repeated once in 5–7 years. Maximum water level of 1% recurrence is about 1000 cm. Such water levels were modelled as combination of the maximum runoff observed during ice jams for the entire historical period combined a with powerful ice jam. In this case, half of the city Velikiy Ustyug can be inundated with maximum depths of more than 1.5 m. A similar extreme floods took place on 5th of May, 1998, when the water level at gauge ‘Veliky Ustug’ reached 980 cm; during flood of 2016 maximum water level 926 cm above gauge datum was observed on 18th of April.
An analysis of different types of levees has shown that such constructions on the one hand should be rather long (more than 5 km) and correspondingly expensive; on the other hand, they will lead to significant flow constriction and concentration on the floodplain. Comparison of the levee construction cost with potential economic damage from floods has shown, that the construction of flood control dams for the cities located on the banks of the Northern Dvina are effective only at a very high floods (1% recurrence). Flood risk management for this area should be based on the combination of the reducing of the ice jam component during spring flood, increasing of the channels capacity by annual channels dredging, and implementation of the hydrological modeling for real-time flood characteristics forecasting.