Calculation of unsteady water movement during flood control

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Abstract. The water was released on a small river of the Leningrad region, observations of the water level dynamics and calculations of wave subsidence and discharge transformation were carried out. Also, we compared the wave parameters with the values, which were obtained by using the model of unsteady water movement. Calculations of the flood control were made on the adapted model for the Shirokii Channel and the Khemchik River.

1. Introduction
During water release in reservoirs, the waves form on rivers, which have influence on settlements situated in tail-bay, bridges, water intakes, etc. Thereby, the determination of water release wave has practical importance. Efficacy of the methods to natural conditions can be controlled by wave release studying in these conditions. These researches were held in USSR in the middle of the 20th century on various objects [1-3]. If the calculation method gives appropriate results, it can be used for designing constructions, where few field observations are made and it is necessary to give regime recommendations in a short time.

Calculations of unsteady water movement in rivers, i.e. calculations of water release and floods are associated with meeting the needs of various sectors of the economy. It is especially important to estimate maximum water levels at various gauges (because of danger of flooding settlements, bridges, roads, plants), and minimum ones (to provide river navigation and normal water intake).

In this research, the water was released on the river Oredezh, and for calculation of release wave distribution model of unsteady water movement was used (numerical scheme developed by IH of the SB RAS). On base of this model calculations of Shirokii Channel and the Khemchik River were conducted for planning and surveying assessments.

2. Study areas
The Oredezh River is a right-hand tributary of the Luga River in the Leningrad region in the Baltic Sea basin. In the upstream, the river is controlled by karst and dams of former hydroelectric power plants.

The Shirokii is a major channel in the Stavropol Territory, located in the basin of the Kuban River. It waters the eastern section of the Armavir corridor, irrigates its fields and replenishes the Surkul River with water. OAO “Sevkavgiprovodkhoz“ employees provided initial information for the model such as morphometry of the channel section, initial and maximum discharges and water levels in this section. These field measurements were conducted in 2013-2014. The flooding of the road to Yessentuki begins at a water discharge of 20 m³ / s.
The Khemchik River flows on the territory of the Tyva Republic and belongs to the Yenisei basin. The source of Khemchik is located on the eastern slope of the Kozer Ridge at the peak of 3122 m in the Shapshal Range system. The river flows between two mountain systems – the Western Sayan from the north and the Western Tannu–Ola from the south. According to the hydrological station gauge near village Iyme, the average annual water discharge is 119 m³/s. The length of the river is 320 km with the catchment area of 27000 km² [4].

The task set by the “Ecostandard Technical Solutions” design engineers was to calculate discharges and water levels during the flood in the section of the river from the village Khemchik to the village Kyzyl-Taiga because of frequent flooding.

3. Materials and methods
There are various velocities of wave release: disturbance velocity, velocity of wave crest lag, velocity of certain discharge lag. A one-dimensional model of unsteady water movement (St. Venant's equation) is preferred to use for calculation of water release waves for slowly changing unsteady water movement, when topographic materials are available [5-8].

The water was released on the river Oredezh on 19.06.2017 and consisted of three phases. Water discharge in the river decreased from 3.6 to 2.5 m³/s. The water-level in the reservoir rose up by 3.5 cm in an hour, after that, at 13 o'clock, the catch was raised and within half an hour, until 13.30, the water was released with an average discharge of 4.2 m³/s. At 13.30 the catch was returned to its previous position. Thus, deviations from the average discharge did not exceed 35%. For monitoring of water level dynamics in the river, 7 gauges were organized.

In the applied one-dimensional model, which is described by linear differential equations in partial derivative, the initial hydraulic and morphometric characteristics are set along the entire considered section of the river. This model allows to determine calculated flow characteristics (water level, discharge and average flow velocity, as well as the changing hydraulic and morphometric characteristics of the river bed) throughout the considered river length. The calculation is carried out according to the implicit numerical scheme of the Institute of Hydrodynamics of the SB RAS. The equations and descriptions of the model are given in detail in papers [9-10].

4. Results and discussion
The results of calculated water levels during crests of the negative and positive waves passing on the Oredezh River are presented in table 1.

| № of gauge | Negative wave, m | Positive wave, m |
|------------|------------------|------------------|
|            | measured | calculated | measured | calculated |
| Gauge 1    | 91.66    | 91.80      | 92.01    | 92.00       |
| Gauge 2    | 91.46    | 91.61      | 91.83    | 91.79       |
| Gauge 3    | 91.39    | 91.46      | 91.55    | 91.57       |
| Gauge 4    | 91.23    | 91.30      | 91.35    | 91.37       |
| Gauge 5    | 91.22    | 91.30      | 91.34    | 91.37       |
| Gauge 6    | 91.01    | 91.06      | 91.05    | 91.07       |

Coefficient of roughness was estimated for the whole section in the inverse path, based on the measured river bed morphometry and the water discharge for the 4th gauge. The largest difference between the measured and calculated water levels during the negative wave passing in the cross sections does not exceed 15.0 cm, during positive - 4.0 cm. The larger discrepancy in the calculations of the negative wave is explained by the poor quality of morphometric river bed characteristics measurement, especially significant at low water levels (with an average depth of 0.63 m, the
amplitude of water levels during the releases reached 0.4 m). The accuracy of positive wave calculated characteristics is quite acceptable and is close to measurement accuracy.

Modeling of the Shirokii channel was conducted according to two cases of specifying initial discharges, measured in 2013-2014 years. During flooding in 2017 the employees of OAO “Sevkavgiprovodkhоз” found out that flooding of the road to Yessentuki begins when the discharge in the canal is equal to 20 m$^3$/s. The road to Yessentuki is situated near one of the cross-sections. During modeling, the hydrograph was obtained at all cross-sections of the calculated section. At the cross-section, which is located near the road to Yessentuki, for the first case of the calculation the maximum water discharge during the flood was 31.9 m$^3$/s, for the second case – 37.9 m$^3$/s (figure 1). The maximum flood wave occurrence for the two cases was similar and dates on 10th day.

![Figure 1](insert://image1.png)

**Figure 1.** Calculated hydrograph at 3 cross-section of the Shirokii channel for 2 cases.

![Figure 2](insert://image2.png)

**Figure 2.** Calculated hydrograph at 3, 6 and 9 cross-sections of the Khemchik River.
To calculate the flood regime of the Khemchik river employer provided morphometric data for 10 cross-sections. Water discharges before flooding, maximum during it and duration of the event for the initial cross-section were obtained using the Hydrograph model [11]. The values of the water levels were taken from the Hydrological annual for the corresponding year. The modeling was based on the flood values of 2002, which turned out to be the most significant over the entire observation period on the Khemchik River. The results of the changing water discharges are presented in figure 2.

5. Conclusion
The experiment of water releasing was conducted on the small river and calculations of wave transformation and distribution were carried out for adaptation of the model of unsteady water movement. The resistance parameter was determined both from the Sribnoy table (TU-24-02) and from observational data. The best result was the definition of the parameter from the measured data.

The adapted model was used to calculate flooding zones of the Shirokii Channel and the Khemchik River. For the Shirokii Channel the model displayed the start time of the flooding on the road to Yessentuki and the value of the water discharge. For the Khemchik River, there is a rapid spreading of the flood wave, due to the presence of large floodplain areas. In this case there was no large flooding of the territory. For better accuracy of calculations, it is necessary to make morphometry measurements at the cross-sections in different phases of the water regime, which will allow to obtain more precise values of the roughness coefficient and the river bed morphometric characteristics.

In conclusion, it is necessary to mention that the best results match occurs when the coefficient of roughness is determined from the measured water discharged and the cross-section morphometry (even if it is just one cross-section). The fact that the Hydrological annuals no longer print the tables of the measured water discharge creates more harm for calculation of the unsteady water movement and design calculations. According to the last century data, researchers are trying to determine the hydraulic-morphometric characteristics, but these data do not correspond to modern morphometry and are approximate.

The task for further researches is to assess the impact of the floodplain and bends on the water level regime. For this, it is necessary to identify the borders of the sections in such a way for them to cover, if possible, all the bends of the river.

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