Need for system of protection against floods and high waters in mountain and foothill rivers of the Caucasus

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Abstract. The article presents findings on the estimation of fast-forming floods parameters and hydrological forecasts for short-term changes in water content in the foothill and mountain rivers of southern Russia as exemplified by the Krasnodar Krai. The research aims to provide economic facilities and population with better protection against rapidly forming mixed-origin floods. The need to develop a system of protection against floods and high waters on the mountain and foothill rivers of the Caucasus are considered. The floods in the Tuapse region in October 2010, Krymsk in July 2012, Novomikhaylovsky in August 2012 are taken as an example. The causes of floods and high waters on rivers are different. Precipitation is the main and dominant source of floods and high waters (exclusive of natural and anthropogenic discharge breakthrough floods) in river basins. The North-West Caucasus territory and especially its Black Sea coast is distinguished by rain floods at any time of the year. The main reason for floods is rainfall with an intensity of minimum 50-100 mm/day. Considering that 1 mm of precipitation causes the fallout of 1 liter of water over 1 m² of the earth’s surface, this amount of precipitation is equivalent to the flow of 50-100 liters of water per 1 m² of mountain slopes. The surface of the slopes cannot immediately absorb and hold such an amount of water, and it rushes down into the rivers’ and streams’ beds. An increase in water content leads to a sharp rise in the water level and flooding of the territories adjacent to the river.

1. Introduction
Over the last 30-year, the number of hazardous hydrological phenomena in the Black Sea territory of the Russian Federation has significantly increased. These phenomena cause significant material damage, and in some cases pose a threat to health and human life [1].
The North-West Caucasus and especially its Black Sea coast is distinguished by rain floods at any time of the year. Precipitation is the main and dominant source of floods and high waters in river basins. The slopes surface cannot immediately absorb and hold that amount of water, and it rushes down into the rivers’ and streams’ beds. An increase in water content leads to a sharp rise in the water level and flooding of the territories adjacent to the river [2].

The floods are associated with local heavy precipitation in mountainous areas and pose the greatest danger due to their suddenness. At present, prognostic models enable to calculate frontal precipitation and, accordingly, the associated floods with a sufficient lead time (twenty-four hours) [3]. Forecast of floods caused by local precipitation and tornadoes have a lead time of no more than an hour. Such a
small time interval precludes the full implementation of activities aimed to inform and evacuate the population living in a designated flooding zone [4].

However, the events of recent years show that informing about the approaching hazardous hydrological phenomenon should be with a lead time of at least 2-3 hours [5]. Such an approach is due to the need to take measures to ensure the population safety.

The possible solution to this problem is to obtain reliable initial information on the river behaviour and floods causes.

Initially, it is necessary to solve the problem of constant monitoring of the river waters levels. This will enable to alert the operational services in bad weather, and to maintain control activities, starting with alerting the population, in case of receiving information on an increase in the river water levels.

The fastest are the floods on mountain rivers. They cause the greatest damage due to suddenness. As a rule, they originate from rain or snow with rain.

The supply for the North Black Sea rivers is as follows: rainfall – 54%, melt runoff – 24%, underground supply – 22%. The annual amplitude of water level fluctuations in the rivers of the North Black Sea sector is significant since it is distinguished by regular intense showers [6]. For example, the level of the River Volcano near Arkhipo-Osipovka on November 12, 1980 raised up to 541 cm and exceeded the long-term average for 52 years by 220 cm and the minimum level (noted in 1929 and equal to 137 cm) by 382 cm [7]. The river water level rise was due to a rain flood.

Forecasting in the mountainous zone is complicated by several factors. First of all, local conditions have a significant impact on the formation of cumulonimbus clouds, which cannot yet be considered in forecasting models, as well as the absence of precipitation observation points, which impedes effective verification of calculation methods [8]. The existing radar systems are effective in terms of detecting areas of heavy precipitation in open areas. However, in mountainous terrain, the relief seriously complicates the identification of dangerous clouds.

2. Materials and methods

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On June 20-29, 2002, an outstanding catastrophic flood occurred in the river Kuban basin. It should be noted that in 2002 large floods took place in Europe, Asia, America [9, 10, 11].

The source of catastrophic floods of the upper and middle flows of the river Kuban was areal rainfall of extremely high daily intensity reaching 100 mm/day.

The major cause of the catastrophic flood was the precipitation that fell on the territory of the basin on June 19-20, 2002 [12]. The previous precipitation of June 17-18, 2002 [13] saturated the soils and grounds of the basin to the maximum moisture capacity and led to extremely high runoff coefficients of subsequent precipitation, which sharply increased the catastrophic nature of the flood.

The city of Nevinnomyssk, Barsukovskaya station, Uspenskoe settlement, outskirts of Armavir, Novokubansk and the nearby villages underwent the greatest flooding. The settlements on the left bank of the river Laba in Shovygenovsky and Krasnogvardeisky districts of the Republic of Adygea, specifically, aul Khatukai, hamlets Svobodny and Lesnoy located at the confluence of the river Laba into the river Kuban were flooded as well [14].

In Krasnodar Krai: 8 people died, 40 settlements were flooded, 55 thousand people were evacuate, 76 bridges were damaged, 46 ones were destroyed [15]. More than 2,500 houses were destroyed, 343 km of roads were washed out, 15,000 hectares of arable land were flooded (got under water), more than 2.5 thousand heads of pigs and livestock were killed, 13 gauging stations were destroyed [16].

In the North Black Sea sector, the runoff layer increased from 71 mm (the Gastogay river) to 1,200 mm in the Tuapse. This was due to the floods on the river Tuapse in 1991 and 2010. In general, the rivers of the North Black Sea sector bring from 60% to 70% of the annual runoff during a flood. On
most rivers, the floods are distinguished as spring floods (of thaw origin) [17], summer, autumn and winter ones (of storm origin) [18]. The costs during the flood period exceed the pre-flood ones by 15-53 times. It should be noted that the highest costs for the river Vulan (the settlement of Arkhipo-Osipovka) $Q = 1050 \text{ m}^3/\text{s}$ (1980) [19], river Tuapse (the city of Tuapse) $Q = 950 \text{ m}^3/\text{s}$ (1991) $Q = 1500 \text{ m}^3/\text{s}$ (2010) [20], the discharge was determined indirectly from the traces of the flood in the river bed.

The flood in the Kuban in July, 2012 belongs to the category of outstanding floods. In total, according to the Ministry of Emergency Situations of Russia, 872 residents were rescued, 2,912 people were evacuated. Unfortunately, 171 people died in the emergency zone, the largest number of whom died in Krymsk. This year the village of Krymskaya celebrates its 155th anniversary [21]. Krymsk received the status of the city only on May 28, 1958.

The main reason for the flooding was a heavy shower when a third of the annual rainfall fell in just a day. The daily maximum of precipitation with a recurrence rate of 1 time in 100 years (until July 2012) was as follows:
- 191 mm 292 mm of precipitation fell on July 6 and 7, 2012 for the Neberdzhaevsky reservoir (observations have been carried out since 1959, the observation point for precipitation was set at a height of 170 m);
- 89.5 mm (in July 2012 – 220 mm) for the meteorological station in Krymsk (opened in 1928);
- 173 mm (daily maximum in July 2012 in Novorossiysk – 275 mm, in Gelendzhik – 280 mm) for the weather station Novorossiysk (opened in 1891).

Thus, on August 21, 2012 there was a flood on the river Nechepsukho of the Tuapse District located in Krasnodar Krai near Novomikhaylovsky settlement. 1350 personnel and 222 pieces of equipment were involved in the elimination of the consequences of the flood in Novomikhaylovsky settlement, 80% of them were employees and equipment of the Ministry of Emergency Situations of Russia in the Krasnodar Krai. The eyewitnesses of the flood on the river Tuapse (2010) claimed that the main precipitation was brought by a tornado (whirlwind). However, during a flood on the river Nechepsukho (2012) [22] no information of this kind was reported. Unfortunately, the authors have no information on the amount of precipitation and the coefficient of runoff from the spillway area of the river Nechepsukho. If we assume that the runoff from the spillway area was 100 mm, then the maximum discharge of the river Nechapsukho at the mouth was about 700 $\text{ m}^3/\text{s}$. Emergency prevention services in Novomikhaylovsky had about 7 hours to deploy temporary engineering structures (flexible water-filled long dams up to 3 m high and up to 100 m long) to protect houses and socially significant facilities.

Unfortunately, in recent years, the rivers of the southern slope of the Greater Caucasus have been cleared in insufficient volumes to ensure the safe passage of flood waters. The pollution of the reservoir with sulfates is insignificant and on average for the entire observation period (1990-2016) is 1.1-1.2 MPC. However, these compounds of sulfuric acid salts are the main nutrient for algae and hydrophilous vegetation.

After the events in the Krymsky District in August 2012, the governing body of the Krasnodar Territory decided to create an automated system for monitoring the flood situation on the territory of 29 municipalities located in the Krasnodar Territory at the expense of the regional budget [23]. To create gauging stations, equipment manufactured by OOO “Emersit” was used.

The gauging stations are equipped with non-contact radar sensors with a measurement error of no more than 3 mm. The experience of operating the system in 2013 showed that continuous monitoring of the river water level provides the necessary information content of the operational services, first of all, the Unified Duty Dispatch Service.

The sensor enables to determine the type of precipitation and its intensity in a 10-minute interval. The information is sent on-line to the forecasting unit and to the duty officer of the Unified Duty Dispatch Service of the region. This provides a top-down and bottom-up warning of a hazard.

Thus, the use of actual operational information, a comprehensive assessment of the main parameters contributing to the development of rapidly forming floods and high waters on mountain and foothill rivers of the Krasnodar Krai with the help of Automatic hydrological complexes and
Automatic precipitation gauging complexes will enable to implement effective preventive measures to reduce damage and, most importantly, to save human lives [24].

Operational calculations made by one-dimensional models using the MIKE 11 software package have been worked out in sufficient detail. However, they require large-scale maps M 1:10 000, M 1:5000 and M 1:1000 with the current state of watercourses. Most authors use old maps of scales M 1 100,000 and even M 1:200,000, which do not reflect the current state of watercourses, thus providing rather rough results.

The work highlights the experience of applying digital elevation models using satellite laser scanning. This approach with a set of instrumental sections of watercourses provides the most reliable information when calculating with the help of one-dimensional and two-dimensional models.

Two-dimensional models are effective in substantiating flood zones. It is advisable to use three-dimensional models when justifying the operation of hydraulic structures. For example, we used three-dimensional numerical models when calculating the spillway structures of the Krasnodar reservoir to substantiate the velocity structure in the downstream and make effective decisions to reduce erosion behind the structure in the entire range of the structure’s operation from 70 to 1500 m$^3$/s.

3. Conclusion
The experience of operating the system in 2020 showed that continuous control over the water level of the rivers of the Krasnodar Krai provides the necessary information content concerning the operational services, primarily the Unified Duty Dispatch Service.

However, using only the data of the Automatic Hydrological Complexes does not significantly increase the advance warning of an impending hazardous hydrological phenomenon. In fact, the already formed flood is being monitored. In this case, the advance warning is 0.5-1 hour, no more. Therefore, it is important to determine the parameters that will increase the lead time of warning about rapid floods and high waters in the mountain and foothill rivers of the Krasnodar Krai.

As noted above, the availability of information on precipitation in a particular water collection will allow determining the volume of water entering the river during precipitation. This volume will be determined with a certain degree of error but in a quite acceptable way.

The installation of Automatic precipitation gauging complexes on the territory of Krasnodar Krai will enable to predict the development of the flood situation on rivers with a greater lead time and track its development in detail by linking to a specific watercourse (a flood wave movement) using the existing Automatic hydrological complexes.

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