Analysis of the dependencies of spring flood runoff from the main factors

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Abstract. The article is devoted to study of the conditions of the spring flood runoff formation in high water years. The authors analysed the dependences of the runoff layer on the main factors such as the maximum water storage in the snow before the beginning snowmelt, sum of the positive air temperatures, sum of the precipitation during the spring flood and autumn moistening. It was revealed that the determining factors in the formation of the spring flood runoff layer on the rivers of the Votkinsk catchment are the maximum water reserve in snow and precipitation that fell during this period.

1. Introduction
The process of formation of spring flood runoff is one of the most complex hydrological phenomena, which depends on a large number of zonal and azonal factors. The study of factors determining the magnitude and variability of spring flood runoff is one of the main tasks for the development of hydrological forecasting methods and effective water resources management.

Atmospheric precipitation and air temperature, not only in spring, but also in a very long previous period, are the main factors determining the formation of the spring flood phase. The amount and regime of precipitation fall are determine the degree of autumn moistening, water reserves in the snow cover at the beginning of snowmelt, replenishment of moisture in the pool during snowmelt (fall of liquid and solid of precipitation) [1].

The factors that determine the variability of the maximum flow are of great interest for the development of methods for its prediction [2-3]. Detailed studies of the processes of snowmelt water formation are reflected in [4-7].

The study of B. A. Apollov, G. P. Kalinin, V. D. Komarov showed that the precipitation of the previous autumn period does not participate in the formation of the maximum flow, but strongly influenced on the soil moistening, changing its infiltration ability in spring period [8].

The influence of autumn moistening on the variability of spring runoff is clearly identified for the rivers of the Kulunda steppe in the South of the West Siberian plain. G. V. Pavlenko had obtained close dependence of the coefficient of spring runoff on the amount of precipitation falling from August to the beginning of the winter season [9].

The aim of this study is to analyse the dependences of spring flood runoff on the main factors for the rivers of the Votkinsk reservoir catchment area in high water years.

The catchment area (184240 km²) is located in the North-East of the European part of Russia and covers the basin of Upper and Middle Kama. The right-Bank part of the catchment is on the Russian plain, the left-Bank – in the foothills and on the Western slope of the Ural Mountains. The extent from
North to South is 640 km – from 61°57’ up to 56°05’ northern latitude and from West to East about 530 km from 51°35’ up to 60°27’ east longitude [10]. The catchment is a hilly plain (70%), rising from West to East, where a characteristic feature of the relief is the Western ridges of the Ural mountain country (30% of the total area).

The territory is characterized by pronounced latitudinal zonation in climate change on the plane and altitudinal zonality in Urals [11]. The territory is composed mainly of sedimentary rocks, with the presence of igneous rocks in the Eastern part of the catchment. The largest area is occupied by Paleozoic rocks, especially the Permian system [12-13]. The podzolic soils are dominated (about 78% of the catchment), and the mechanical composition is divided into heavy (clay, loamy) and light (sandy) [14]. The main type of vegetation is forests (dark coniferous, small-leaved and broad-leaved), which occupy about 85% of the catchment [15].

According to the hydrological regime, the rivers of the Votkins reservoir belong to the Eastern European type with a pronounced spring flood, rain floods in the summer-autumn period and winter low water. The predominant river’s feed is snowmelt water [16].

2. Materials and methods
The materials of observations of daily, average monthly and average annual water discharge for 49 gauging stations (g/s) as initial data were used.

The formed database of average annual water discharge covers a multi-year period from the establishment of gauging stations to 2016. The longest period of observation is 80 years for Kama, Kolva and Usva rivers, and 45-70 years for other rivers.

For each gauging station the series with the average annual water flow rates were ranked in descending order. The ranked series were divided into 3 groups: high water years ($P < 33.3\%$), average water years ($33.3\% \leq P \leq 66.7\%$) and low water years ($P > 66.7\%$) according to SP 33-101-2003 [17].

In the high water years group several years (1965, 1971, 1978, 1979, 1984, 1986, 1990, 1993, 1994) were selected as follows: data should be available for most of the gauging stations. All meteorological information has been collected for each of these years.

The investigated characteristic was the value of the layer runoff spring flood $Y$ (mm), and the following indicators were used as the main factors:
- the maximum of water storage in snow $S_{\text{max}}$ before the beginning of snowmelt, mm layer water (determined by snow surveys);
- the sum of the average daily positive temperatures $\Sigma t^+$ from the date of transition of air temperature through 0°C to positive values before the date of the beginning of the water level intensive rise, °C (further the sum of the air temperatures);
- the amount of precipitation during the spring flood $\Sigma x$, mm (it was determined taking into time to get precipitation up to the gauging station);
- the autumn moistening $U$, mm (the value was taken the amount of precipitation for the period from the beginning of autumn floods to the steady transition of the average daily air temperature through 0°C to negative values).

Methods of correlation and regression analysis were used to assess the impact of the main factors.

3. Results
The closest and statistically significant dependences of the spring flood runoff layer separately with each investigated characteristic for 1971, 1978, 1979, 1990, 1993, 1994 high water years are revealed.

Analysis of the annual distribution of river flow in these years showed, they have belonged to the 1st type (high long spring flood and floods in the warm period of the year) or to the 2nd type (high spring flood and minor or absent summer-autumn floods) according to the typification of hydrographs [18]. These years are allocated due to formation of high spring flood – the share of spring flood flow in the annual was more than 50%.
In the years: 1965, 1984 and 1986 the main role in the formation of high average annual water discharge belongs to precipitation in the summer-autumn period. Hydrographs of these years belong to the 3rd type (low spring flood and significant summer and autumn floods) (figure 1).

Figure 1. Spatial distribution of different types of hydrographs in high-water years:
1st type – the northern and mountainous part (Kama, Veslyana, Lupya, Pilva, Vishera, Kolva, Yazva, Yayva, Kosva);
2nd type – the south-western part (Tulva) and south-eastern part (Sulva, Irgina, Babka, Iren, Barda, Chusovaya, Sylem, Sylva, Koiva, Vizhay, Usva);
3rd type – the central part (Urolka, Kondas, Inva, Kuva, Velva, Obva, Ocher, Guyva, Mulyanka).

The maximum of water storage in snow and precipitation during the flood are the main determining factors of formation the high spring flood on the rivers of the Votkinsk reservoir catchment. It has been traced in all selected years (table 1). If by the beginning of the snowmelt formed large reserves of water in snow, the layer of the spring flood runoff will also be large. The larger the water storage in snow by the beginning of the snowmelt, the more flow layer of the spring flood. Precipitation fallen during this period contribute to increase the spring runoff.

The tightness of the dependence $Y = f(U)$ is much lower. Because the autumn moistening has an indirect effect on the amount of the layer spring flood runoff – with a large autumn moistening water losses for infiltration during snowmelt are reduced.

The dependence $Y = f(\sum t_e)$ is characterized by the lowest correlation coefficients, since the course of air temperature also has an indirect effect on the value of the layer spring flood runoff (table 1, figure 2). This factor has a greater impact on the maximum spring flood formation: with increasing the
amount of accumulated positive air temperatures the snowmelt intensity increases, which leads to a rapid rise of water level.

**Table 1.** The correlation coefficients $r$ by dependencies on the main factors.

| Factors     | 1971  | 1978  | 1979  | 1990  | 1993  | 1994  |
|-------------|-------|-------|-------|-------|-------|-------|
| $S_{max}$   | 0.72  | 0.87  | 0.90  | 0.71  | 0.73  | 0.80  |
| $\sum T$   | 0.32  | 0.57  | 0.46  | 0.11  | 0.43  | 0.30  |
| $\sum x$   | 0.64  | 0.64  | 0.70  | 0.74  | 0.70  | 0.76  |
| $U$         | 0.69  | 0.62  | 0.47  | 0.44  | 0.67  | 0.34  |
| $S_{max} \cdot U$ | 0.82  | 0.75  | 0.83  | 0.79  | 0.79  | 0.75  |
| $S_{max} \cdot \sum x$ | 0.73  | 0.77  | 0.86  | 0.82  | 0.81  | 0.79  |
| $S_{max} \cdot \sum x \cdot U$ | 0.82  | 0.81  | 0.85  | 0.83  | 0.85  | 0.75  |
| $K = S_{max} \cdot \sum x \cdot U \cdot \sum T$ | 0.77  | 0.69  | 0.74  | 0.83  | 0.85  | 0.78  |

Note: statistically significant correlation coefficients are shown in bold italics.

**Figure 2.** The dependence of the spring runoff layer on the main factors and their complex impact in 1994.
4. Discussion
A study of the possibility of integrated consideration of the main factors was carried out. These factors are independent of each other and their impact on the amount of spring flood flow is directly proportional, which is why the joint account in form of a product of these indicators is possible.

The assessment of the effect of the maximum water storage in snow and precipitation during the flood on the spring flood runoff layer showed that these dependences \( Y = f(S_{\text{max}} \cdot \sum x) \) are statistically significant and characterized by high correlation coefficients \( r = 0.73 \div 0.86 \).

When adding the value of autumn moistening \( U \) to \( Y (Y = f(S_{\text{max}} \cdot \sum x \cdot U)) \) the tightness of the dependence slightly increases.

Taking into account the influence of all studied factors is possible in the form of a complex parameter \( K = S_{\text{max}} \cdot \sum x \cdot U \cdot \sum t \), which is the product of the values of the maximum water storage in the snow, precipitation, autumn moistening, reducing the infiltration of melt water in spring, and the sum of the air temperatures, which determines the intensity of the snowmelt process. The obtained dependence is statistically significant; however, an increase in the number of factors reduces the closeness of the dependence (table 1).

5. Conclusion
The main factors of the spring flood runoff formation in the rivers of the Votkinsk reservoir catchment are the maximum supply of water in snow before the snowmelt and precipitation during the spring flood. The value of the autumn moistening and the sum of the air temperatures \( \sum T \) has an indirect effect.

The analysis of the possibility of complex accounting of all studied factors on the spring flood runoff formation in the form of \( Y = f(S_{\text{max}} \cdot \sum x \cdot U \cdot \sum t) \) showed that this does not significantly increase the connection tightness. The highest correlation coefficients are obtained from the dependences \( Y = f(S_{\text{max}} \cdot \sum x) \).

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