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SURFACE AND GROUND WATERS IN TERRESTRIAL PERMAFROST REGION

ASSESSMENT OF THE AMOUNT OF WINTER PRECIPITATION IN MOUNTAIN BASINS AND THEIR INFLUENCE ON FLOOD FORMATION (CHARYSH AND ANUY RIVER BASINS, ALTAE AS A CASE STUDY)

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The paper presents an estimate of the annual precipitation amount for the winter period (1967–2006) in the basins of the Charysh and Anuy mountain rivers. A kinematic model for air mass movement when crossing orographic barriers is used for calculations. The initial data are monthly precipitation totals (November–March) obtained from meteorological stations and gauges located within the basins and at the adjacent territory. Based on the single-factor dependencies and multiple correlation/regression analysis, we assess the dependences of melt runoff depth on total precipitation for winter and flood (April–June) time periods in the gaging stations "Charyshsky state farm" on Charysh River and "Anuysky state farm" – on Anuy.

Keywords: *Altai, Charysh River, Anuy River, winter precipitation, high water, runoff depth.*

INTRODUCTION

Climatic changes in the last decade have had a significant impact on the water regime of high and middle-latitude rivers, especially during high water. This is primarily due to a change in the amount of solid sediments, a shifting of the periods and a decrease in the duration of snow cover [*Barnett et al., 2005; DeWalle, Rango, 2008; Shiklomanov, 2008*]. An increase in temperatures during the cold period and, as a consequence, a decrease in the depth of seasonal soil freezing cause an increase in water content in the low season and a decrease in melt runoff in spring due to infiltration losses [*Shiklomanov, 2008; Kalyuzhny, Lavrov, 2012*].

There has been a decrease in the annual flow rate of rivers up to 5–22 % in the rivers of the Ob basin since the 1970s [*Shiklomanov, 2008*]. At the same time, the frequency of unfavorable hydrological processes associated with flooding of the settlements during high water and rain floods [*Puzanov et al., 2018*].

The main task for hydrological forecasts is to estimate snow reserves in the catchment basin since up to 70 % of the flood runoff is formed by the meltwater [*Apollov et al., 1974*]. Traditionally, in hydrological studies, the amount of precipitation in mountainous areas is linked to the absolute height of observation points [*Kharshan, 1970; Revyakin, Kravtsova, 1977; Mukhin, 2013*]. In recent decades, snow storage distribution models have been used, including a number of terrain characteristics (height, slope aspect, slope gradient, distance to the orographic barrier, etc.) [*Li et al., 2015; Samoilova, Galakhov, 2020*], as well as landscapes [*Gensiorovsky, 2007*], or combination of these parameters [*Lubenets, Chernykh, 2019*]. This approach is successful when the data from snow-amount surveys are used.

Remote sensing methods are widely used, but in mountainous areas, they give satisfactory results only together with field observations [*Iglovskaya, Narozhny, 2010; Romasko, Burakov, 2017; Churyulin et al., 2018*].

A network of instrumental observations in Altai does not cover the watershed areas and slopes of mountain ranges where maximum snow reserves form.

This work is part of a study on the assessment of snow reserves and forecasting of flood runoff in mountain rivers of the Upper Ob basin. The previously developed methodology [*Galakhov, 2003*] makes it possible to estimate the amount of winter precipitation in mountain basins under the lack of hydrometeorological information. The technique has been successfully used in hydrological calculations and medium-term forecasts of water levels in the Charysh River [*Galakhov et al., 2016, 2018*]. In spite of the fact that the volume of the flood and the maximum water levels depend on the same factors (water reserves in the snow cover, liquid precipitation of the flood and the water absorption capacity of the basin) [*Popov, 1979*], their relationship is not always unambiguous. The intensity and course of snowmelt in the basin have a substantial influence on the formation of levels, and, as a result, the rate of the meltwater flow into the river network, as well as congestions.

In this paper, we assess winter precipitation in the basins of the Charysh and Anuy rivers using the author's model of the snow reserve distribution in complex orography conditions. To verify the simulation results, the relationship between the amount of winter precipitation and the flood volume expressed in the runoff layer is analyzed.

STUDY OBJECTS

Two basins of the Charysh and Anuy rivers (Fig. 1), the 1st order left tributaries of the Ob River, which are located within the Altai Mountainous region, were selected as study objects. Both basins are located on the northern macro slope of the Altai Mountainous region and have absolute heights of 150–200 m in the lower course, up to 2000–2300 m and more in the upper course (Fig. 1).

The basin of the Charysh River. The source of the Charysh River is located at the junction of the Korogonsky and Seminsky ridges at an altitude of 1800 m. From the north, the basin is bounded by the Bashchelak ridge, from the south by the Tigiretsky and the Korgonsky ranges of the northern Altai (1800–2300 m). The basin area is 22 000 km^2, the length of the river is 547 km, and the average slope is 3 ‰. Conventionally, the basin can be divided into two parts: mountainous down to the village of Karpovo (13 900 km^2) and foothill part (smaller in the area). Close to the gaging station "Charyshsky state farm", the Charysh River basin has an area of 20 700 km^2, and its average height is 750 m. The woodiness of the basin is 15 %. The average long-term flow rate is 193 m^3/s, the maximum is 2650 m^3/s (1958). The flood is multi-peak. As a rule, it lasts from the end of March to the second decade of July with a maximum in late May-early June. The share of flood runoff in annual runoff is 51–84 % [*Surface, 1975*].

The Anuy River basin is bounded by the Baschelaksky ridge to the west and by the Anuy ridge to the east. The length of the river is 327 km, and the total area of the basin is 6930 km^2. The catchment area up to the gaging station "Anuysky state farm" is 4870 km^2, the average height of the catchment is 790 m, and the average slope of the river is 5.1 ‰. The woodiness of the basin is 20 %. The average long-term flow rate is 31.1 m^3/s, the maximum is 462 m^3/s (1966). The flood is multi-peak, lasts from the end of March to the end of June, and reaches its maximum in the third decade of April. On average, 42 to 73 % of

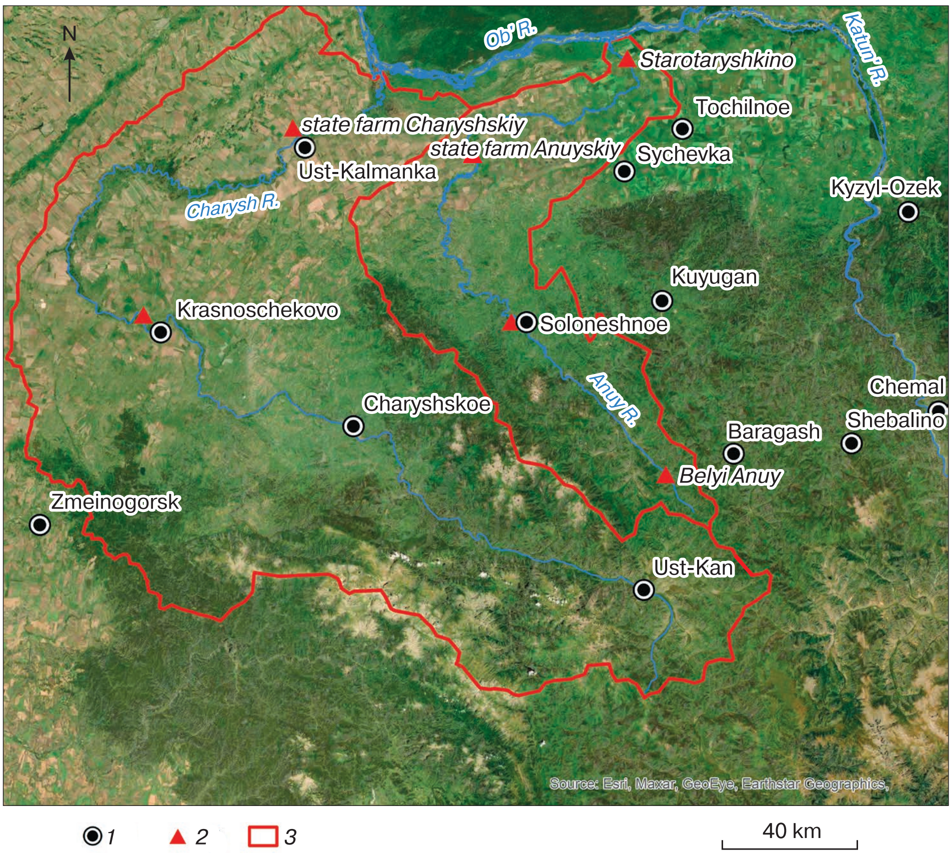

Fig. 1. Basins of the Charysh and Anuy rivers.

1 – hydrometeorological stations and posts; *2* – hydrological posts; *3* – borders of the Charysh and Anuy river basins.

the annual runoff passes during the flood [*Suface, 1975*]. In contrast to the basin of Charysh river, the catchment area of the Anuy River to the gaging station "Anuysky state farm" is entirely comprised by low mountains and middle mountains, there is a foothill plain downstream with an area of about 2,000 km^2.

RESEARCH METHODS AND INITIAL DATA

Traditionally in hydrological studies, the amount of precipitation is linked to the absolute height of observation points [*Kharshan, 1970; Revyakin, Kravtsova, 1977; Mukhin, 2013*]. The verification of this pattern in the basins of the Charysh and Anuy rivers has revealed the absence of a statistically significant relationship between winter precipitation and an absolute altitude in most years [*Galakhov et al., 2020*]. In addition, the highest weather station in the Charysh River basin is Ust-Kan (1037.4 m), in the Anuy River basin the highest is Kuyagan post (560 m), and the maximum absolute heights in the basins reach 2000 m or more. Thus, it is impossible to interpolate annual winter precipitation in the studied basins based on their dependence on absolute height.

Estimation of precipitation amounts for the cold period using an orographic additive to the speed of the air-mass vertical movements. The influence of mountains on atmospheric fronts is diverse. It is manifested through the detention of atmospheric fronts, the change in the speed of a particular front section movement, the aggravation of fronts, formation of frontal waves in the front of the windward side of the ridge and the erosion of frontal zones when they pass over the ridges. Quite a peculiar is a process associated with the circumference of the frontal zone of an orographic obstacle [*Shakina, 1985; Galakhov, 2003*].

It is known that the intensity of precipitation depends on the speed of the air flow vertical movements [*Rogers, 1979*]. It is very difficult to determine the speed of vertical movements due to the processes occurring in the cloud mass itself. But it is possible to determine the addition to the speed of vertical movements of air masses (i.e., the change in the speed of vertical movements of air masses due to the orography) during the formation of solid precipitation using fairly simple kinematic models.

Earlier the authors have developed a simplified kinematic model of the distribution of solid precipitation in the complex orography based on the principles of the movement of air flows skirting an obstacle or passing over it, described in [*Barry, 1964; Rogers, 1979; Skorer, 1980; Matveev, 1981, 1984*]. It requires a minimum set of input data, including the absolute height of the underlying surface, taken from the topographic base map with a certain grid spacing, the speed and direction of the upcoming atmospheric fronts, as well as the temperature of the surface air layer taken from the aerological station records. The algorithm and a detailed description of the model are published in [*Galakhov, 2003*]. This method of calculation is applicable only to winter conditions when the temperature of the underlying surface is negative and more or less uniform, additionally, in the conditions of low and medium-height mountains (elevations no more than 2 km). In the studied basins, this condition is generally satisfied.

Based on this model, a territory matrix with a grid spacing of 25 × 25 km is created for the basins of the Anuy and Charysh rivers. In the lower-left corner of each grid cell, average orographic additives to the speed of air-mass vertical movements during the formation of solid precipitation were calculated (Fig. 2), and for the rest of the area they were determined by interpolation. The values of the orographic additive for the research area vary from −1 m/s (Ust-Kansk basin) to 0.75 m/s or more (the area of Zmeinogorsk) and depend, first of all, on the slopes of the surface, the absolute height of the terrain, as well as the speed and direction of the flows of the prevailing air masses [*Galakhov, 2003*]. This matrix allows to interpolate precipitation data from weather stations and posts for the entire territory of the basin, taking into account the orographic additive.

The calculation of the average amounts of winter precipitation in the basin was carried out as follows. At the initial stage, the amount of winter precipitation X was determined for each year at meteorological stations and posts located within the studied basins and on the adjacent territory. The sum of winter precipitation is taken as the sum of precipitation from November 1 to March 31. Data sources are meteorological monthly and materials of the websites of Roshydromet (http://aisori.meteo.ru/) and "Weather and Climate" (http://www.pogodaiklimat.ru). The research period was determined by the availability of meteorological monthly reports and data on surface runoff, which were later used for "hydrological control".

Further, based on the obtained values of X and the orographic additive to the speed of vertical movements of V_z in the area of weather stations, a dependence of $X = f(V_z)$ was constructed.

Then, the average amount of winter precipitation in the cells was estimated using the obtained regression equations $X = f(V_z)$ and the orographic addition of V_z in each grid cell of the matrix (Fig. 2).

For the Charysh River basin, the period 1967–1981 was analyzed, including years with extreme water content: 1969 was close to a maximum, 1974 was close to a minimum, as well as the period 1993–2001 and 2006. The list of meteorological stations, their absolute heights, as well as the values of the orographic additive and the average long-term precipitation for the winter months are presented in Table 1.

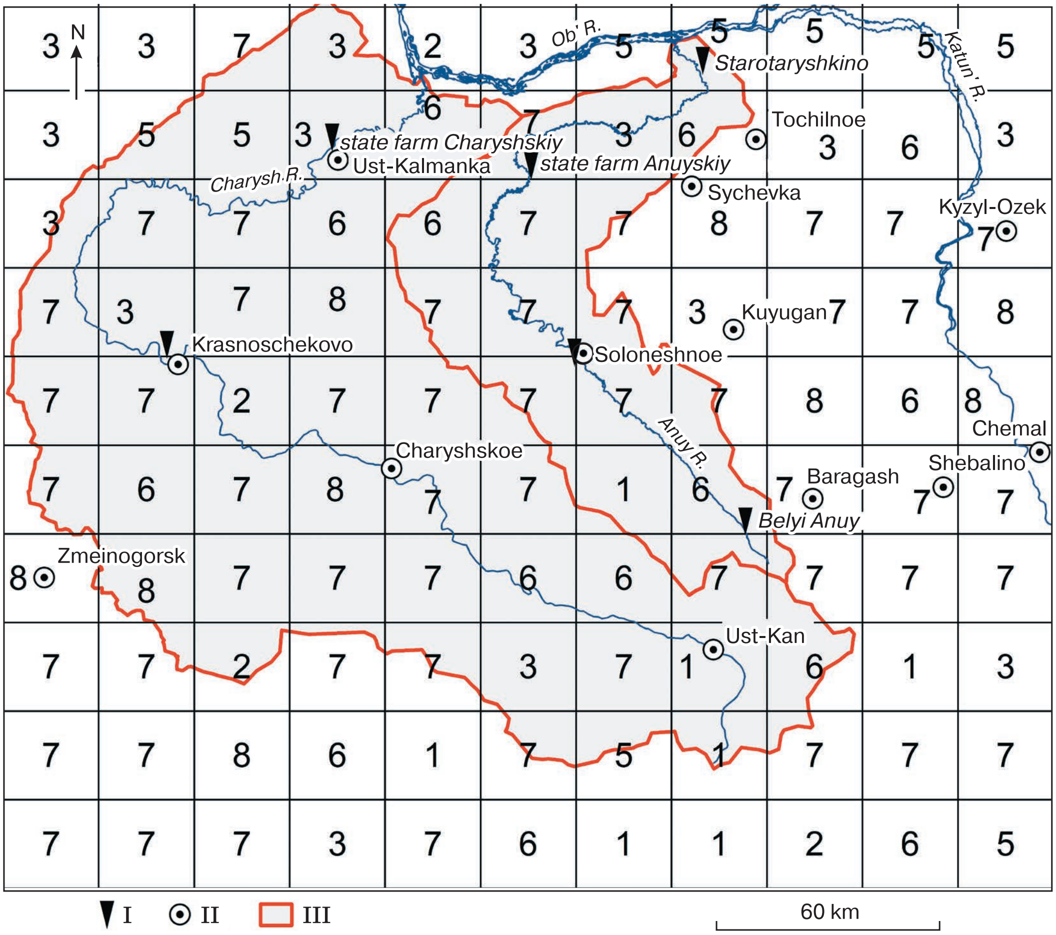

Fig. 2. Matrix of orographic additive to the speed of vertical movements of air masses in the basins of the Charysh and Anuy rivers.

1 – from −1.0 to −0.5 m/s; 2 – from −0.5 to −0.1 m/s; 3 – from −0.1 to −0.01 m/s; 4 – from −0.01 to 0 m/s; 5 – from 0 to 0.01 m/s; 6 – from 0.01 to 0.1 m/s; 7 – from 0.1 to 0.5 m/s; 8 – from 0.5 to 1.0 m/s m/s. The orographic additive value refers to the lower left corner of the cell. Meteorological stations and posts within the studied basins are shown: I – hydrological, II – meteorological; III – basin boundaries.

For calculations on the Anuy River basin, a shorter period was chosen: from 1967 to 1974 and from 1981 to 1988, as there are meteorological monthlies only for these years, which makes it possible to include data on meteorological posts in the calculation of precipitation fields. Also, by analogy with the Charysh River basin, calculations were additionally performed (without data on posts) according to weather station data for the period from 1993 to 2001 and 2006. The list of weather stations and posts which data were used to calculate precipitation fields in the Anuy River basin is given in Table 2.

When determining the amount of winter precipitation for each weather station, the need for a correction for the blizzard transfer was assessed on the basis of the ratio of snow reserves according to landscape snow-amount surveys and the precipitation meter (the coefficient of blizzard transfer). Most

Table 1. **Weather stations used to calculate the amount of winter precipitation (November–March) in the Charysh River basin**

Weather station or post	Absolute height*, m	Average long-term amount of precipitation*	V_z, m/s
Zmeinogorsk	354.6	164	0.75
Krasnoshchekovo	240	116	0.30
Charyshskoe	400	103	0.41
Soloneshnoe	400	150	0.25
Chemal	410	60	0.27
Shebalino	870	63	0.30
Ust-Kan	1037.4	35	–0.03

Note: V_z – orographic additive. Weather stations are given in italics.

* According to [*Directory..., 1969*].

Table 2. **Weather stations used to calculate the amount of winter precipitation (November–March) in the Anuy River basin**

Weather station or post	Absolute height*, m	Average long-term amount of precipitation*, mm*	V_z, m/s
Ust-Kalmanka	149	–	0.0
Krasnoschekovo	240	116	0.3
Charyzhskoe	400	103	0.41
Soloneshnoe	400	150	0.25
Starotyryshkino	167	108	0.05
Tochilnoe	200	148	0.055
State farm Anuysky	–	–	0.1
Sychevka	225	113	0.2
Kuyagan	560	140	0.2

Note: V_z – orographic additive. Weather stations are given in italics.

* According to [*Directory..., 1969*].

Table 3. **Dependence of the blizzard transfer oefficient on the maximum snow cover height, Ust-Kalmanka weather station**

Year	Date of accumulation of maximum snow reserves	Maximum snow reserves, mm	The amount of winter precipitation, mm	The coefficient of blizzard transfer
1968/69	20 March	76	178.7	0.43
1972/73	20 March	71	132.7	0.54
1974/75	10 February	24	31.7	0.76
1975/76	20 March	81	119.0	0.68
1978/79	15 March	82	173.2	0.47

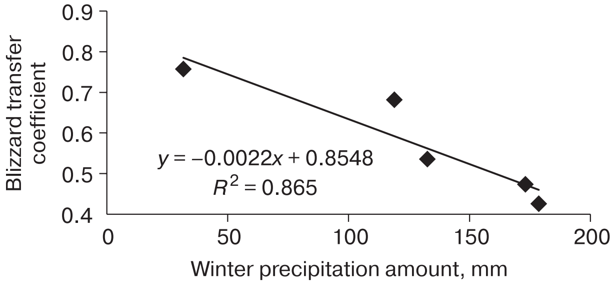

Fig. 3. Dependence of the blizzard transfer coefficient on the amount of winter precipitation measured by snow gauge (weather station Ust-Kalmanka).

weather stations have either a blizzard transfer coefficient close to 1.0 or is constant from year to year, which indicates the absence of a blizzard concentration. According to the Ust-Kalmanka state meteorological station, the coefficient varies in different years from 0.43 to 0.76 (Table 3).

At the same time, a statistically significant dependence of the blizzard transfer coefficient on the amount of winter precipitation was found (Fig. 3). This dependence was used to account for the influence of the snowstorm concentration at this meteorological station, as well as at the posts of the foothill plain located in similar conditions: Starotyryshkino, Tochilnoe, state farm Anuysky and Sychevka, because there are no enough snow-survey data in these points.

Thus, the calculation of the annual amount of winter precipitation was carried out for all meteorological stations (posts) taking into account the correction for blizzard transport. Regression equations in the form $X = f(V_z)$ were obtained.

An example of the dependence $X = f(V_z)$ for the winter of 1973/74 in the basin of the Charysh River and the basin of the Anuy River is shown in Fig. 4.

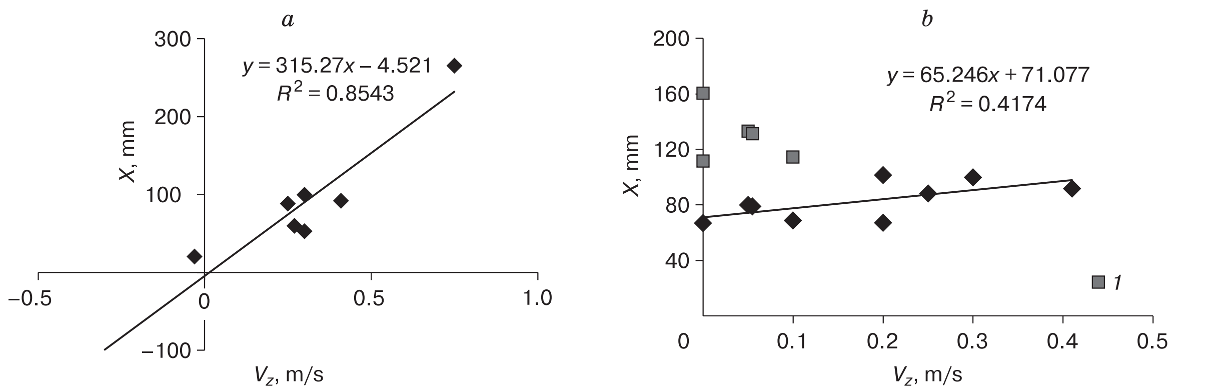

Fig. 4. Dependence of the amount of winter precipitation (X) in the winter of 1973/74 in the Charysh River basin (*a*) and the Anuy River basin (*b*) on the orographic additive to the speed of vertical movements of air masses (V_z).

The squares (*1*) show the sum of winter precipitation for meteorological stations and posts without taking into account the blizzard concentration (Ust-Kalmanka, Starotyryshkino, Tochilnoye, state farm Anuysky, Sychevka).

Table 4. **The determination coefficients between the amount of winter precipitation and orographic additive, Charysh River basin**

Winter	R^2	F	Winter	R^2	F
1967/68	0.66	15.75	1968/69	0.85	40.22
1969/70	0.91	70.87	1970/71	0.79	15.0
1971/72	0.63	13.69	1972/73	0.72	22.65
1973/74	0.85	29.3	1974/75	0.44	5.45
1975/76	0.57	10.81	1976/77	0.55	17.4
1977/78	0.62	11.28	1978/79	0.60	7.58
1979/80	0.84	43.03	1980/81	0.70	9.26
1993/94	0.75	11.77	1994/95	0.85	23.0
1995/96	0.76	12.3	1996/97	0.73	10.69
1997/98	0.80	16.0	1998/99	0.64	7.14
1999/00	0.87	32.27	2000/01	0.69	8.79
2005/06	0.66	9.7	2005/06	0.66	9.7

Table 5. **The determination coefficients between the amount of winter precipitation and orographic additive, Anuy River basin**

Winter	R^2	F	Winter	R^2	F
1967/68	0.63	15.8	1968/69	0.37	4.06
1969/70	0.26	2.50	1970/71	0.01	0.06
1971/72	0.75	18.25	1972/73	0.37	3.54
1973/74	0.42	5.02	–		
1980/81	0.52	7.65	1981/82	0.59	10.14
1982/83	0.52	7.68	1983/84	0.18	1.56
1984/85	0.30	2.51	1985/86	0.34	3.10
1986/87	0.05	0.30	1987/88	0.20	0.98
1993/94	0.78	6.99	1994/95	0.97	62.01
1995/96	0.45	1.64	1996/97	0.98	138
1997/98	0.92	25.77	1998/99	0.38	1.25
1999/00	0.52	2.20	2000/01	0.50	1.96
2005/06	0.89	16.53	2005/06	0.89	16.55

The quality control of each equation was carried out by standard methods using the coefficient of determination R^2 and Fisher's F-criterion, determined as

$$F = \frac{R^2}{1-R^2}(n-2), \qquad (1)$$

where n is the number of observations.

The determination coefficients and criterion F for each winter season are presented in Tables 4 and 5.

At meteorological stations in the basin of the Anuy River, the amount of winter precipitation for a single year do not have such a high amplitude as in the basin Charysh (Fig. 4). Therefore, in most cases, the statistical relationship with the orographic additive is much weaker (Table 5).

After calculating the amount of precipitation in each cell of the matrix, the basin average value of the amount of winter precipitation for each year was estimated (Tables 6, 7).

Assessment of the impact of precipitation on flood runoff. The evaluation of the calculation results for winter precipitation was carried out according to the principle of "hydrological control" based on the analysis of their relationship with the volume of high water expressed as the runoff layer.

The data on the flood runoff layer before 1980 were taken from the reference books of the state water cadaster [*Surface, 1969; Surface, 1975; Surface, 1984*], later was calculated by the authors using daily water flow rate data from hydrological yearbooks and the website of the Information and Analytical Center of the Register and Cadaster (http://gis.vodinfo.ru/).

The relationship between the runoff layer and the precipitation of the cold period was estimated using one-factor dependencies and by means of multiple correlation and regression analysis. The amounts of winter precipitation in the basin, calculated using an orographic additive, as well as the amount of precipitation for the flood period, calculated from monthly precipitation data, accounting for the average flood periods, are taken as predictors.

Table 6. **Precipitation amount during winter (November–March) and flood period (April–June) and the flood runoff layer, the Charysh River – gaging station "Charyshsky state farm"**

Hydrological year	Precipitation amount, mm		Flood runoff layer, mm	High water period
	November–March	April–June		
1967/68	113	152	193	16.03–08.07
1968/69	174	233	387	11.04–19.07
1969/70	81	230	248	25.03–06.08
1970/71	99	251	309	25.03–03.08
1971/72	96	225	229	03.04–07.08
1972/73	101	228	305	28.03–19.07
1973/74	88	121	119	29.03–10.06
1974/75	54	176	232	29.03–19.07
1975/76	88	137	144	14.04–22.06
1976/77	110	161	182	31.03–21.06
1977/78	74	192	171	18.03–23.07
1978/79	77	221	208	15.04–08.07
1979/80	64	190	142	09.04–13.07
1980/81	82	112	118	18.03–14.07
1993/94	74	235	190	26.03–20.06
1994/95	110	276	223	26.03–06.07
1995/96	58	197	184	09.04–05.08
1996/97	80	103	160	26.03–12.06
1997/98	71	252	–	–
1998/99	63	236	156	03.04–21.07
1999/00	66	272	172	28.03–21.07
2000/01	94	263	259	22.03–31.07
2005/06	106	152	231	27.03–23.07

Table 7. **Precipitation amounts for winter (November–March) and flood period (April–June) and the flood runoff layer, the Anuy River – gaging station "Anuysky state farm"**

Hydrological year	Precipitation amount, mm		Runoff layer, mm		Floods	High water period
	Novermber–March	April–June	with rain floods	without rain floods		
1967/68	112	147	113	107	15–23.05	14.03–21.06
1968/69	158	231	225	225	–	06.04–06.07
1969/70	75	213	118	79	13.05–05.06	21.03–04.07
1970/71	87	173	126	115	09–15.05; 18–30.05	25.03–18.06
1971/72	94	203	90	90	–	05.04–29.06
1972/73	101	261	161	140	16.05–08.06	23.03–20.06
1973/74	76	125	62	62	–	28.03–9.06
1980/81	88	121	63.3	63	–	21.03–24.06
1981/82	70	265	63.2	61	06–13.05	01.04–01.06
1982/83	66	244	82.3	78	24.05–06.06	22.03–12.06
1983/84	65	240	56.7	49	19.05–05.06	16.04–26.06
1984/85	80	191	92.2	92	–	28.03–15.06
1985/86	79	175	93.7	91	07–11.05; 03–10.06	05.04–21.06
1986/87	71	175	97.2	96	17–21.05; 24–28.05	03.04–18.06
1987/88	81	197	109.7	98	15.05–10.06	22.03–24.06
1993/94	74	201	97	80	27.04–01.05;11–20.05;22–30.05	11.03–01.07
1994/95	121	263	155.9	139	19–29.05; 02–24.06	20.03–01.07
1995/96	69	192	72	70	27–28.04; 04–06.05; 23–27.05	11.04–11.06
1996/97	78	159	90.5	87	09–21.05	18.03–10.06
1997/98	80	233	79	73	02–06.05; 18–23.05; 11–13.06	09.04–21.06
1998/99	69	201	67	65	07–15.06	28.03–25.06
1999/00	84	234	106	101	05–07.05; 13–16.05; 06–08.06	25.03–01.07
2000/01	102	245	124	121	01–02.05; 19–22.05	19.03–29.06
2005/06	112	282	171.2	160	28.04–06.05; 17–22.05; 27.05–01.06	29.03–14.06

runoff, since the conditions during this runoff are generally similar [*Burakov, Ivanova, 2010*]. The end of snowmelt was determined according to a complex graph as the moment of violation of the correspondence between the course of temperatures and water flow rate, when an increase in temperatures does not cause an increase in flow rate [*Kharshan, 1970*]. On the decline of the flood, rain floods formed by liquid precipitation that had fallen after the end of snowmelt were distinguished. The allocation of rain runoff on the hydrograph was done by "cutting off" individual peaks (floods) with subsequent exclusion when calculating the flood runoff layer.

On the Charysh River, the flood is multi-peak and more extended in time, which is associated with a wide variety of landscapes and climates, so it is often impossible to identify rain floods on the hydrograph. The flood runoff layer for the Charysh River is calculated taking into account rain floods.

RESULTS AND DISCUSSION

Tables 6 and 7 present calculations of winter precipitation amount, precipitation from April to June period, and the flood runoff layer for each year.

The results of the calculation of winter precipitation amount and the flood runoff layer (Tables 6, 7) were analyzed using statistical methods of correlation and regression analysis. At the first stage, correlation matrices and graphs of the dependence of the flood runoff layer on the amount of winter precipitation for the Anuy and Charysh rivers were constructed (Fig. 5).

Correlation analysis showed that the amount of winter precipitation is the main factor in the formation of flood runoff: in general, the Anuy River basin is characterized by a closer relationship between winter precipitation and runoff (r = 0.87) than the Charysh River basin (r = 0.64). The "cut off" of rain floods on the decline of the flood for the Anuy River has increased, as expected, the closeness of the relation (r increased to 0.91). Liquid precipitation during the decline of the flood period, which forms rain floods, is second in importance. Moreover, according to the results of correlation analysis, both for Anuy and Charysh rivers, the highest correlation coefficient of flood runoff is observed with summarized monthly precipitation from April to June (inclusive). The inclusion of liquid precipitation in July for the Charysh River reduces the correlation with the flood runoff.

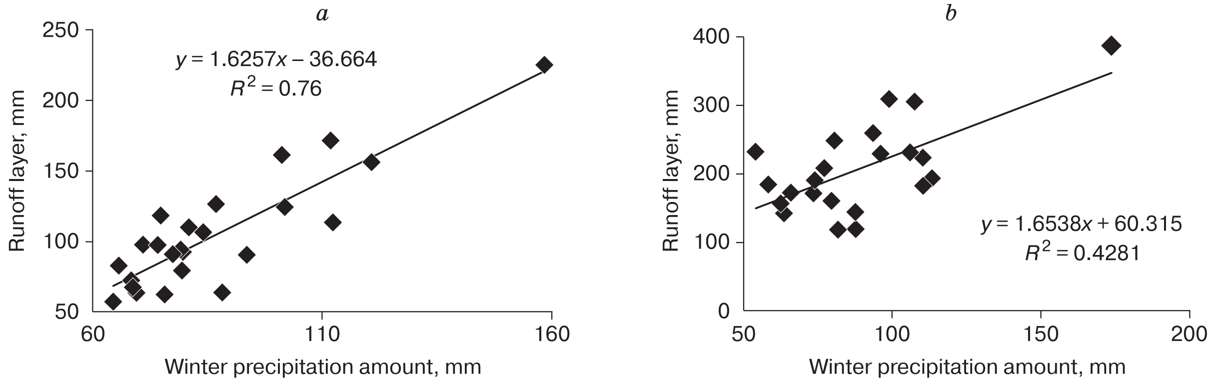

Fig. 5. Dependence of the flood runoff layer of the Anuy River (*a*) and the Charysh River (*b*) on the amount of winter precipitation (November–March).

Obviously, this may be due to more significant losses for the evaporation, the transpiration, wetting of vegetation and the filtration into soils in July (compared to May–June). It is noted that for the Anuy River, liquid precipitation contributes significantly less to the formation of high water ($r = 0.37$) than for the Charysh River ($r = 0.58$).

At the second stage, the results of correlation analysis were used to develop multiple linear regression equations based on two significant predictors: the amount of winter precipitation (from November to March) calculated using an orographic additive, and the amount of precipitation during the high water period (April to June) at a representative meteorological station. The parameters of the equations for the Anuy and Charysh rivers are given in Table 8.

In general, for the Anuy River equation is as follows:

$$h = 1.53P_1 + 0.21P_2 - 72.1 \quad (2)$$

and for the Charysh River is:

$$h = 1.47P_1 + 0.64P_2 - 49.3, \quad (3)$$

where h is the layer of runoff for the flood (mm), P_1 is the amount of winter precipitation (mm), P_2 is the rainfall period, floods (mm).

The values of the coefficients of determination $R^2 = 0.81$ $\left(R^2_{\text{norm}} = 0.79\right)$ and the Fisher criterion $F = 45.05$ (critical value $F = 3.47$ at a significance level of 5 %) in the equation for Anuy River (2), indicate a high level of reliability. For the Charysh River, the quality of equation (3) is somewhat worse: $R^2 = 0.67$, $R^2_{\text{norm}} = 0.63$, $F = 18.4$ (critical value 3.55), but it also explains the dependence of the runoff layer on precipitation quite well. Both equations can be used as a predictive model. The less close relationship of the main predictor with the runoff and the worse quality of the multiple regression model for the Charysh River are associated with a significant influence on the flood runoff of the factors determining the water absorption capacity of the river basin, which are not taken into account in the model.

Previous works of the authors have shown that the initial period of snow accumulation plays an important role in the formation of maximum flood levels in the Charysh River basin. If the thickness of the

Table 8. **Regression statistics and coefficients of the multiple linear regression equation**

Parameter	Coefficient value	Coefficient standard error	Multiple R	R^2	Normalized R^2	F-test	Number of years
	Flood runoff of Anuy River (accounting rain floods)						
Free term	–72.1	21.75	0.90	0.81	0.79	45.05	24
P_1, mm	1.53	0.18					
P_2, mm	0.21	0.09					
	Flood runoff of Charysh River (with account of rain floods)						
Free term	–49.28	44.09	0.82	0.67	0.63	18.14	21
P_1, mm	1.47	0.35					
P_2, mm	0.64	0.17					

Note: P_1 is the sum of winter precipitation (November–March); P_2 is precipitation during the high water period (April–June).

snow cover before the onset of significant frosts (below −10 °C) is more than 20–25 cm, and there is no significant seasonal freezing of rocks in the basin, then in the spring period in the gaging station of the state farm Charyshsky maximum levels observed are 1 meter lower compared to years when meteorological conditions contribute to seasonal freezing [*Galakhov et al., 2018*].

Studies of the conditions for the formation of snow cover in the Anuy River basin, carried out using similar methods, indicate no influence of seasonal freezing on the flood runoff [*Galakhov et al., 2020*]. According to the authors, such significant differences in the processes of melt runoff formation in two neighboring basins are associated with their geomorphological features. The basin of the Anuy River to the state farm Anuysky gaging station is represented by middle and low mountains only, which, as a rule, are distinguished by higher and constant coefficients of melt runoff [*Apollov et al., 1974; Burakov, 1986*]. About 40 % of the Charysh River basin is a foothill plain, which is characterized by a large variability of melt runoff coefficients depending on the state of soils in the basin (rock composition, moisture content, depth of seasonal freezing) and, as a consequence, melt runoff losses for infiltration.

CONCLUSION

1. As shown earlier [*Galakhov et al., 2020*], in the basins of the Anuy and Charysh rivers, in most cases there is no statistically significant dependence of the amounts of winter (November–March) precipitation according to hydrometeorological stations and posts on their absolute height. The use of an orthographic additive to the speed of air mass vertical movements for calculating the amount of winter precipitation is preferable. For the Charysh River basin, there is a close relationship between the amount of winter precipitation and the orographic addition to the speed of air mass vertical movements both on a multi-year scale and in individual years. Statistically insignificant coefficients of determination between the amount of winter precipitation and an orographic additive in the Anuy River basin in some cases are associated with a more uniform distribution of precipitation fields within the basin.

2. The analysis of the dependence of the winter precipitation amounts obtained using an orographic additive and the flood runoff layer performed by the authors earlier [*Galakhov et al., 2020*] has shown their close ($R^2 = 0.76$) relationship in the Anuy River basin. The accounting of rain floods on the decline of the flood was carried out in two ways: by the method of their "cut-off", and the introduction of an additional predictor into the regression equation, the amount of precipitation from April to June on the Soloneshnoye Station, that has allowed increasing the determination coefficients to 0.83 and 0.81, respectively. All this, firstly, confirms the reliability of calculations of precipitation amounts. Secondly, it allows us to conclude that winter precipitation is the main factor affecting the volume of flood runoff in the Anuy River basin.

3. In the Charysh River basin, the relationship between the amounts of winter precipitation and the volume of runoff is much weaker ($R^2 = 0.43$). Correlation analysis has shown that for the Charysh River, liquid precipitation from April to June has a greater effect on the volume of high water than for the Anuy River. The introduction of high-water precipitation (April to June) into the regression equation significantly improved the quality of the model ($R^2 = 0.67$, $R^2_{\text{norm}} = 0.63$). In general, in comparison with the Anuy River basin, the relationship between runoff volume and precipitation is less significant. This is due to the fact that about 40% of the basin is located on the foothill plain, which is characterized by a large variability of melt runoff coefficients depending on the condition of the soils (their composition, degree of moisture, freezing). This hypothesis requires confirmation and further research.

4. The obtained multiple regression equations confirm the reliability of winter precipitation calculations and can be used for medium-term forecasts of flood volume on the Anuy and Charysh rivers. At the same time, in a mountain basin with relatively homogeneous landscape and climatic conditions (the Anuy River), it is acceptable to use a one-factor correlation dependence of the flood runoff on the amount of winter precipitation. For the Charysh River basin, which has a complex geomorphological structure, it is necessary to introduce additional predictors into the model that characterize the precipitation of the flood period and the condition of soils that determine their infiltration ability.

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