

A METHOD FOR CALCULATING THE HYDROLOGICAL PARAMETERS OF STORMWATER RUNOFF IN MOUNTAINOUS AND FOOTHILL REGIONS

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Abstract:

This article investigates the development of a digital model of the relief of the Achchiksoy basin, located in the territory of the Kyzylcha Rural Settlement of the Dehkanabad district of the Kashkadarya region, and the determination of its morphometric parameters. The study examines the method of mathematical modeling of the topographic surface of the Achiksai River basin territory based on reference points. In forming the digital model of the basin's relief, approaches to

topographic surface discretization, the use of interpolation functions, and the formation of mathematical expressions based on elevation features were utilized. Based on the proposed mathematical expression, a numerical experiment was conducted on the experimental parameters of the Achiksai River basin and a digital model of its relief was developed. The results obtained allow for the assessment of the relief features of the Achchiksoy River basin, the determination of morphometric parameters, and their use in research related to the effective use of water resources in the region.

Keywords: Achchiksoy; Achchiksoy basin; relief; digital relief model; DEM; morphometric parameters; topographic surface; mathematical modeling; interpolation; elevation marks; numerical experiment.

Introduction

The relief of mountainous and foothill areas where seasonal streams form possesses complex topological features consisting of various degrees of slope. Therefore, methods for calculating the hydrological and hydrodynamic parameters of water flow formed by atmospheric precipitation in areas with high slopes have not been sufficiently studied.

Within the framework of the scientific work, based on field research conducted between 2023 and 2025, the main parameters of the hydrological and topological features of seasonal streams formed in the mountainous Kitab, Kamashi, and foothill Dehkanabad districts of the Kashkadarya region were investigated.

Based on the research goal, we are improving the method for calculating the main hydrological parameters of streams formed by rainwater in mid-mountain areas with high terrain slopes using the Achchiksoy basin in the Dehkanabad district of the Kashkadarya region, where the experimental studies were conducted.

The slope of the terrain is an important morphological parameter and is measured mainly in percent. In the literature of V.A. Nikolaev and A.G. Isachenko, the characteristics of terrain slopes have been well-studied, namely:

1. slope of hills and adyrs – 3.5–8.7%;
2. Low mountains - 9 - 26.7%;
3. Middle and High Mountains – 26.7%<.

Based on the condition of the problem, we perform mathematical modeling using experimental parameters of the hydrological, topographical, and morphological features of the research object with a terrain slope of 26.7% or more.

In this region, atmospheric precipitation, such as rain and torrential rains, falls primarily in March-May. Precipitation during this period averages 450–550 mm.

The object of the study is the Achchiksoy River basin, which is a medium-mountain territory with a relief slope of 26.7% or more (Fig. 1).

In the Achchiksoy River basin, rainfall occurs mainly in April-May of the spring season. Rainfall is the primary factor in the formation of water flow and groundwater along the slopes of the territory. Consequently, to calculate the main hydrological parameters of the runoff formed by rainwater in a water body with large slopes, we divide it into elementary areas (Fig. 2).

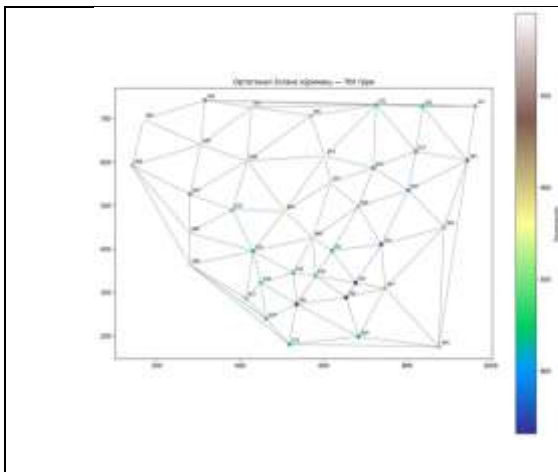


Figure 1. Inclination Degree of the Achchiksoy River Basin

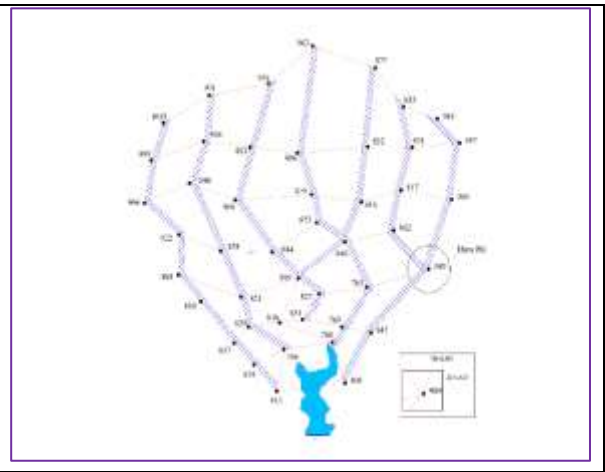


Figure 2. Isochrones of a water flow moving along a slope

Thus, we determine the volume and velocity of water moving at high velocity along the slope along the elementary surface ΔS (isochrone) shown in Fig. 2. When modeling, we take into account the following simplifications and assumptions. That is, the depth of the water flow moving along the elementary surface ΔS at time t is z , and the intensity of the rain is θ . Let the intensity of energy loss of the flow be I . Suppose that the intensity of rainfall and the energy loss of the flow are time-dependent functions and are constant over the area of the basin. Based on the assumptions set forth above, we construct the water balance of the flow forming in the elementary field ΔS at the moment Δt . Consequently, at time Δt , the amount of water flow on the elementary surface ΔS is expressed as follows.

$$\Delta(z \cdot \Delta t) = \frac{d(z \cdot \Delta S)}{dt} \cdot \Delta t \quad (1)$$

$\theta - I$ If the difference in equation (1) is taken into account, then

$$\frac{d(z \cdot \Delta S)}{dt} \cdot \Delta t = \Delta S(\theta - I) \cdot \Delta t \quad (2)$$

From equation (2), we have:

$$z \cdot \frac{d(\Delta S)}{dt} + \Delta S \frac{dz}{dt} = \Delta S(\theta - I) \quad (3)$$

$\Delta S = f(I)$ then, will be

$$I = u \cdot \tau.$$

Here: $I\tau$ is the distance from the isochrons of the flow moving along the slope to the axis of the seasonal stream, and y is the velocity of the flow moving along the slope, representing the time during which the flow reaches the axis of the seasonal stream from the isochrons.

Assuming $y = \text{const}$, we have $\Delta S = f(t)$ or $\Delta S = f(t)$.

$$\Delta S = \frac{ds}{d\tau} \Delta \tau = s' \Delta \tau \quad (4)$$

Here:

$$s' = \frac{ds}{d\tau}$$

Substituting expression (4) into expression (2), we obtain:

$$z = \frac{ds'}{dt} + s' \frac{dz}{dt} = s'(\theta - I) \quad (5)$$

Dividing equation (5) by s' prime, we obtain the following equation.

$$z = \frac{s''}{s'} + \frac{dz}{dt} = \theta - I \quad (6)$$

Here:

$$s'' = \frac{ds'}{dt}.$$

Equation (6) takes into account the parameters of two reference systems for time. That is, τ and t are absolute time. Therefore, it is advisable to reduce time to a single reference system. Here, τ increases from the basin's water content to the seasonal stream axis $[0, \tau]$, while t -absolute time increases in the opposite direction. Then the following conditions are met:

$$\begin{cases} d\tau = -dt \\ \frac{ds'}{d\tau} = -\frac{ds'}{dt} \\ \frac{dz}{d\tau} = -\frac{dz}{dt} \end{cases} \quad (7)$$

We bring the system of equations (7) to equation (6) and, as a result, obtain:

$$z = \frac{s''}{s'} + \frac{dz}{dt} + \theta - I = 0 \quad (8)$$

As a result, we obtain a differential equation describing the movement of a flow moving along a slope in mid-mountain areas.

We seek the solution of differential equation (8) in the following form:

$$z = \exp \left[- \int \frac{s''}{s'} d\tau \right] \cdot \left[A - \int (\theta - I) \cdot \exp \left(\int \frac{s''}{s'} d\tau \right) d\tau \right] \quad (9)$$

We introduce the following notation into equation (9):

$$\begin{cases} \exp \left[- \int \frac{s''}{s'} d\tau \right] = \frac{A_1}{s'} \\ \exp \left[\int \frac{s''}{s'} d\tau \right] = \frac{s'}{A_1} \end{cases} \quad (10)$$

Then equation (9) will take the following form:

$$z = \frac{A_1}{s'} \left[A - \int (\theta - I) \frac{s'}{A_1} \cdot d\tau \right] \quad (11)$$

Here, A and A_1 are indefinite integral constants.

Now let us integrate equation (11) from τ to 0:

$$z = \frac{s'_0}{s'} \left[z_0 - \int_{\tau}^0 (\theta - I) \frac{s'}{s'_0} d\tau \right] \quad (12)$$

From equation (12), it follows that:

$$zs' - z_0 s'_0 = \int_0^{\tau} (\theta - I) s' d\tau \quad (13)$$

We determine the values $z s'_0$ and s'_0 in equation (13):

$$z_0 s'_0 = z_0 \left(\frac{ds}{d\tau} \right)_0 = z_0 \left(\frac{\partial s}{\partial l} \right)_0 \left(\frac{\partial l}{\partial \tau} \right)_0 \quad (14)$$

Along with that

$$\begin{cases} \left(\frac{\partial s}{\partial l} \right)_0 = s_0 \\ \left(\frac{\partial l}{\partial \tau} \right)_0 = - \left(\frac{\partial l}{\partial t} \right)_t = -u_0 \end{cases} \quad (15)$$

From the system of equations (15), we have:

$$z_0 \cdot s'_0 = -z_0 \cdot s_0 \cdot u_0 = -q_0 \quad (16)$$

here: q_0 is the water flow rate of the downpour flow moving down the slope.

Similarly, (16) we have:

$$zs' = -z_{\tau} \cdot s_{\tau} \cdot u_{\tau} = q_{\tau} \quad (17)$$

By reducing expressions (16) and (17) to equations (13), we obtain:

$$-q_{\tau} + q = \int_0^{\tau} (\theta - I) s' d\tau \quad (18)$$

It is located on the watershed section of the reservoir territory. As a result, we obtain the following equation:

where: $q_{\tau} = 0$ is the water flow rate of the downpour flow moving along the slope;

$$q = \int_0^{\tau} (\theta - I) \frac{ds}{d\tau} d\tau \quad (19)$$

In the watershed section of the reservoir territory, $q_{\tau} = 0$. As a result, we obtain the following equation:

$$\Delta t = \frac{\tau}{B} \quad (20)$$

Here: B is the parameter determined from expression (18).

As a result, we obtain:

$$q_t = \sum_{k=1}^m S / \tau_k (\theta - I)_k \quad (21)$$

Thus, we obtained expression (21) to calculate the flow rate of rainwater formed from the slopes of the seasonal stream basin over a certain period of time. The adequacy of this expression is substantiated by comparing its numerical solutions with the results of research conducted in practice. The comparison error averaged 5.6%. The comparison diagram of the results is presented in Figure 3.

Improved approximate method for calculating the hydrological parameters of small rivers and streams without the presence of hydrometric observation data

Currently, there are more than three thousand seasonal small rivers and streams in our country, of which about two thousand are tributaries of regulated rivers. Hydrometric observations are conducted only on approximately 10% of the aforementioned small rivers and streams.

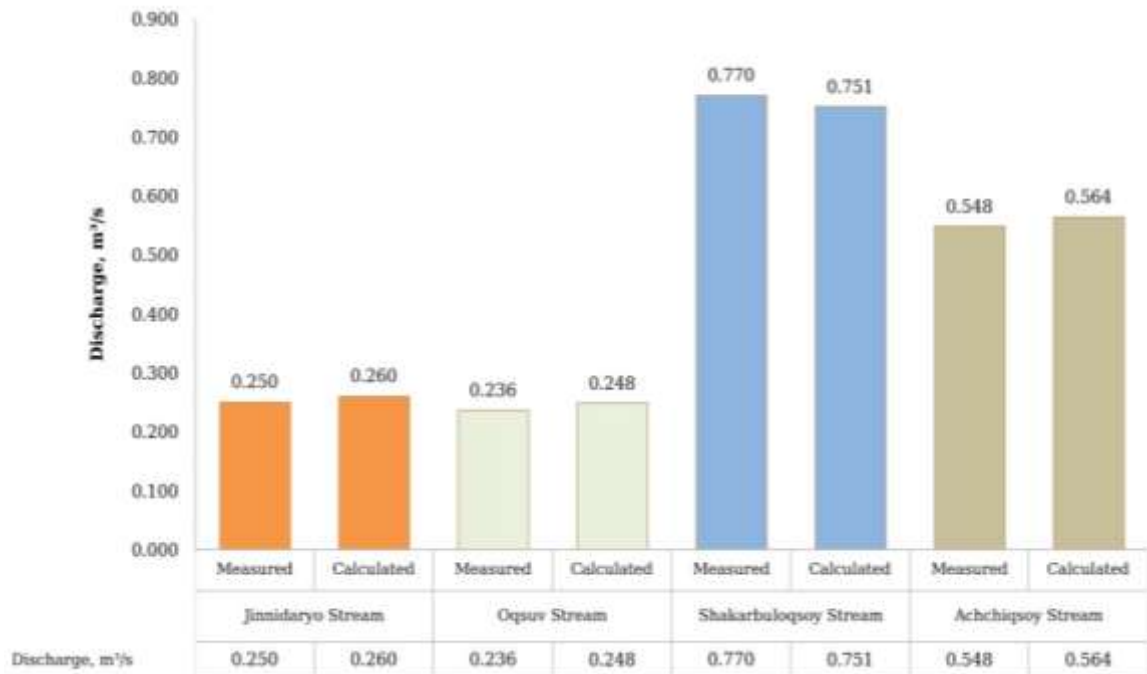


Figure 3. Graph of comparison between natural water discharge and calculated water discharge in the seasonal rivers of the research object

Determining the hydrological characteristics of small rivers and streams where hydrometric observations are not conducted is a complex task. Approximate methods are primarily used for this purpose. Currently, there are many methods for calculating the hydrological parameters of small rivers and streams, for which there are no data from hydrometric observations. Based on the improved calculation methods based on experimental and theoretical research conducted within the framework of the scientific work, a forecast of the main hydrological parameters of the water flow formed during

various water supply in the seasonal streams of Achchiksay, Shakarbulaksay, Aksuvsay, and Jinnidaryasay, which are the objects of research, was carried out.

The calculation results are presented below in the form of a table and a graph.

Table 1. Hydromorphometric characteristics of the Shakarbulaksay riverbed

$\Xi \text{ km}^2$	$L, \text{ km}$	$I_{\text{river}}, \%$	m	m_p	φ	H_p	Φ
3,7	7,4	0,77	0,12	7,3	0,4	5	6,9

Table 2. Significance of hydrological and morphological characteristics of the watercourse bed in Shakarbulaksai

C	n_2	n_3	φ_0	φ	m	m_p	H_p	Φ	δ	q_t
0,78	0,44	0,059	0,18	0,4	0,12	7,3	59,2	6,9	0,7	0,02

Table 3. Water consumption provision indicators of the Shakarbulaksay River.

Indicators	Sufficiency, P, %				
	1%	2%	3%	5%	75%
Q, l/sec	4700	2300	1150	600	62,2

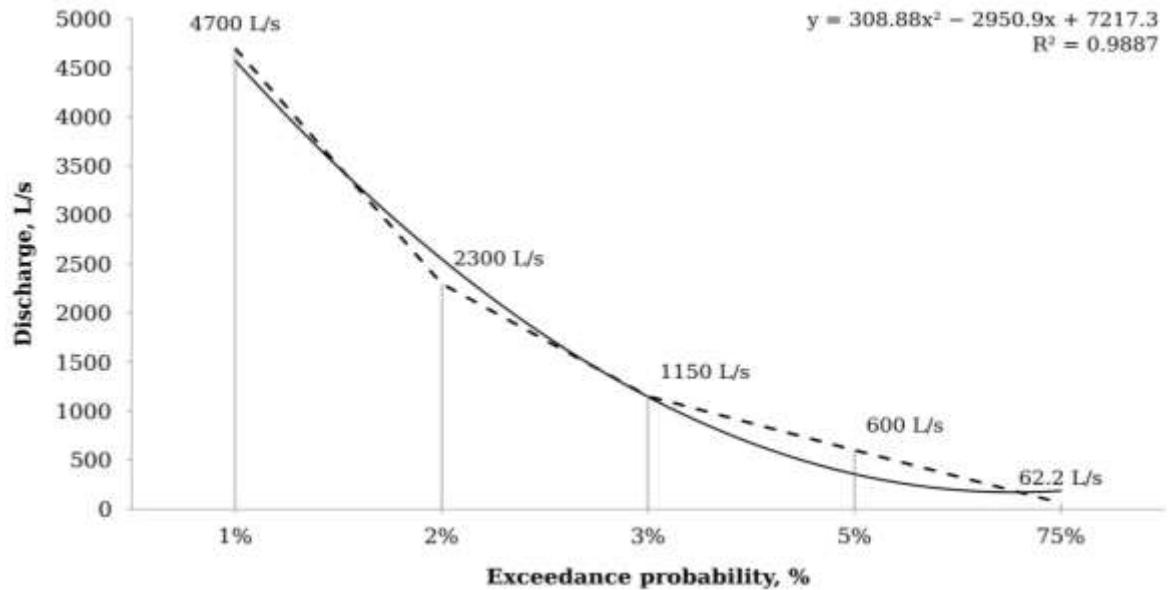


Figure 4. Provision indicators for long-term water consumption of the Shakarbulak seasonal stream, %

Table 4. Hydromorphometric characteristics of the Achchiksai River bed

$\Xi \text{ km}^2$	$L, \text{ km}$	$I_{\text{river}}, \%$	m	m_p	φ	H_p	Φ
1,8	5,7	2,1	0,2	7,1	0,47	6	14.

Table 5. Significance of hydrological and morphological characteristics of the water flow channel in the Achchiksoy River

C	n_2	n_3	φ_0	φ	m	m_p	H_p	Φ	δ	q_t
0,2	0,6	0,072	0,28	0,47	0,2	7,1	6	14	1	0,03

Table 6. Water Supply Indicators of the Achchiksoy River.

Indicators	Sufficiency, P, %				
	1%	2%	3%	5%	75%
Q, l/sec	580.	290	150	80	7,7

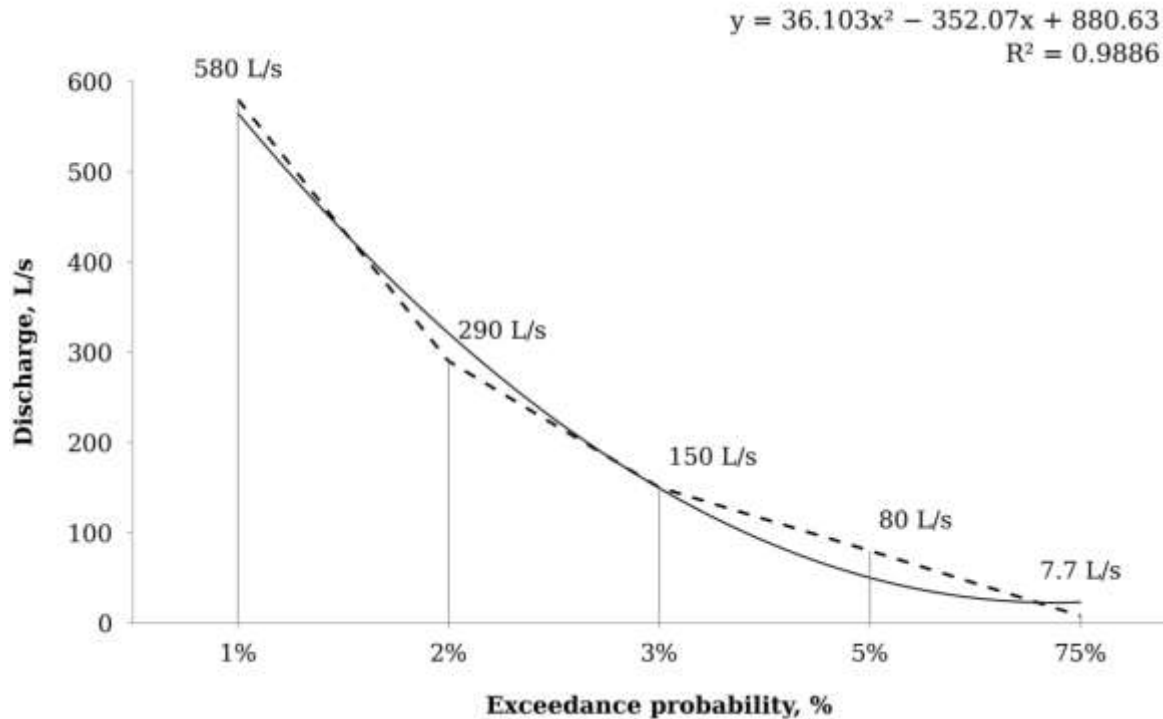


Figure 5. Indicators for ensuring long-term water consumption of the Achchiksoy seasonal stream, %

Table 7. Hydromorphometric characteristics of the Jinnidaryasay riverbed

$E \text{ km}^2$	$L, \text{ km}$	$I_{\text{river}}, \%$	m	m_p	φ	H_p	Φ
2	0,85	0,69	0,08	2,9	0,35	4	4,6

Table 8. Significance of hydrological and morphological characteristics of the water flow channel in Jinnidaryasay

C	n_2	n_3	φ_0	φ	m	m_p	H_p	Φ	δ	q_t
0,69	0,4	0,052	0,15	0,35	0,08	2,9	4	4,6	0,64	0,01

Table 9. Water Supply Indicators of the Jinnidaryasay River.

Indicators	Sufficiency, P, %				
	1%	2%	3%	5%	75%
Q, l/sec	750	380	190	100	9,9

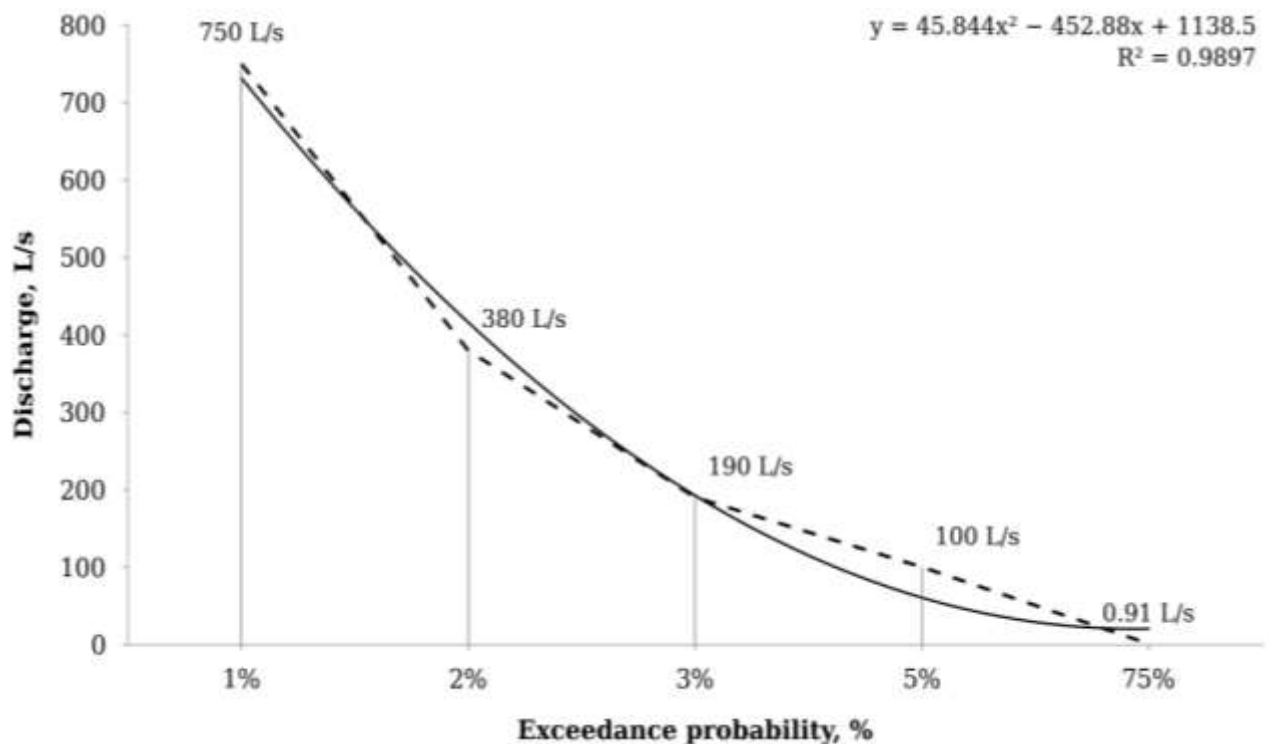


Figure 6. Indicators of ensuring long-term water consumption of the seasonal Jinnidaryasay stream, %

Table 10. Hydromorphometric characteristics of the Oqsuvsoy soy bed

E km ²	L , km	I_{river} , %	m	m_p	φ	H_p	Φ
2,8	0,75	0,5	0,08	2,3	0,29	46,3	4,2

Table 11. Significance of Hydrological and Morphological Characteristics of the Watercourse Bed in the Aksu Say

C	n_2	n_3	φ_0	φ	m	m_p	H_p	Φ	δ	q_t
0,65	0,37	0,042	0,12	0,29	0,08	2,3	46,3	4,2	0,69	0,016

Table 12. Indicators of water consumption provision for the Aksovsay River.

Indicators	Sufficiency, P, %				
	1%	2%	3%	5%	75%
Q, l/sec	170	80	40	20.	2,3

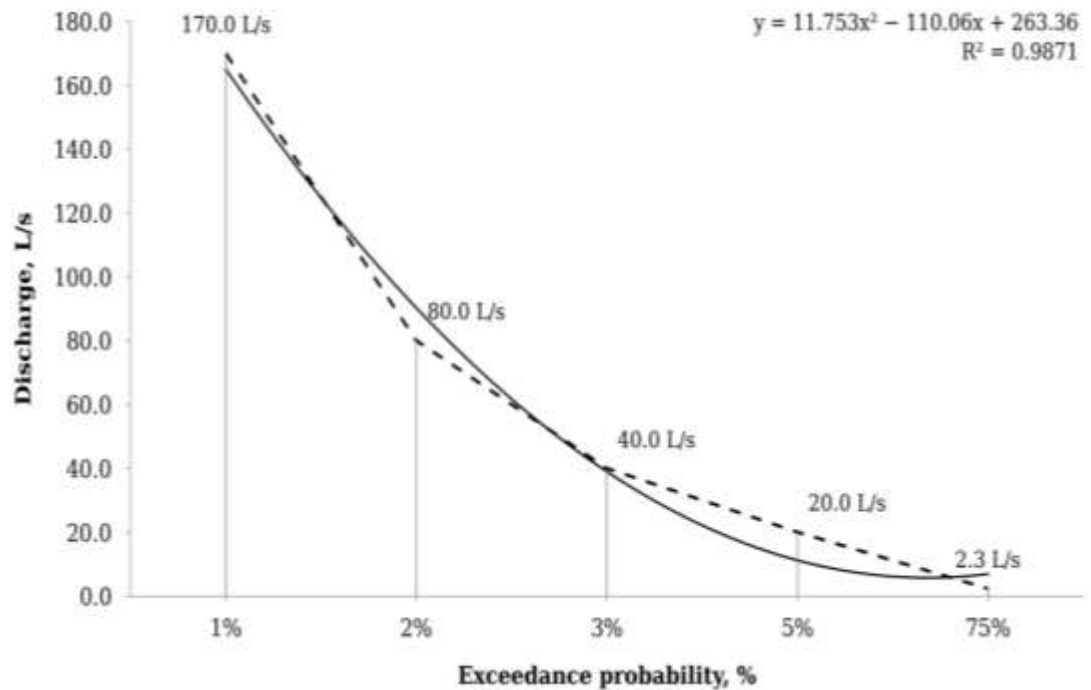


Figure 7. Indicators for ensuring long-term water consumption of the seasonal Aksuay stream, %

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