INTRODUCTION
At present, during the period of intensive climatic changes, it is important to thoroughly take into account the hydrological regimes of water bodies. One of the major conditions of ensuring hydrological safety of territories is a reliable forecast of stream-channel deformations and channel-related processes in the case of water bodies and their separate sections. This paper reviews different methods of calculating bed load discharge. Thus, a new technique of calculation of bed load discharge was developed with consideration of the probabilistic estimate of the beginning of bed load motion. The method shows satisfactory results compared to previous techniques in use.

TECHNIQUE OF CALCULATIONS AND RESULTS
For conducting reliable forecasts of stream-channel deformations, it is necessary to more precisely calculate bed load discharge. However, due to the low precision of measurements, imperfection of techniques and meters, measuring of bed load discharge \( P_{\text{bc}} \) is stopped in the stationary hydrological networks of many countries, including Kazakhstan, a long time ago.

Several publications and normative documents on identification of hydrological characteristics contain hundreds of formulas for determination and calculation of bed load discharge value. However, as a rule, for the same conditions they give different results and there is a considerable difference between bed load discharge values. At the same time, lack of data on \( P_{\text{bc}} \) value may seriously affect engineering calculations and reliability of recommendations on ablation assessment, taking into account load transport and forecast of deformations in the channels of water bodies. Under these circumstances, it is necessary to continue the work on improvement of the methods of accounting sediment transport and enhancing forecasts of channel processes [Duskaev 1997, 1995, Mikhalev et. al. 1988, 1975].

The proposed technique of calculating bottom sediment discharge in the case of mountain rivers was been developed based on the stochastic method of assessment of the beginning of motion...
of separate particles and sediment transport on the river bed.

The calculation is dependent on determining the probability of particles becoming loose due to the stream tearing them off from the river bed.

$$P = A \left( \frac{Re_s}{Ar^n} \right)^m$$

(1)

where:

$$Re = \frac{U_s \cdot d}{v}$$

(2)

is Particle Reynolds number (characterizing a stream);

$$Ar = \frac{gd^3}{v^2} \left( \frac{\rho - \rho_s}{\rho} \right)$$

(3)

is Archimedean number (particles sizes);

$$Sh = \frac{U_s \cdot t}{d \cdot N}$$

(4)

is Strouhal number (duration of a stream impact on particles).

Indication in dependences:

A, n, m – empirical coefficients;

$U_s$ – friction velocity;

d – particles average diameter;

t – duration of a stream impact on particle

$N$ – number of particles in the surface layer of the investigated river bed section;

$\rho, \rho_s$ – density of water and sediment;

$v$ – kinematic coefficient of water viscosity;

$g$ – acceleration of gravity [Duskayev 1988, Mikhalev 2013].

The detailed description of the technique of calculation of bottom sediment discharge, based on the stochastic method of assessing the beginning of motion of separate particles and sediment transport on the river bed is given in [Mikhalev 1975, Duskayev 1988, Veksler 2020].

For the purpose of checking the reliability of calculations made in compliance with the proposed technique, comparative calculations of the values of bottom sediment discharge were carried out according to the formulas of different authors; at the same time, the best known dependences were used.

As reference values of bed load discharge, the data, based on the measurements of bed load discharge made by Kromer R.K. on the mountain rivers of South Kazakhstan (Turgen River, Esik River, Kaskelen River, Talgar River and other rivers) were selected. Bed load discharge has been measured by Kromer R.K. with the help of volumetric method in water-intake facilities zone, this fact allows considering that precision of his measurements is rather high.

In this investigation, with the use of the main morphometric characteristics of stream and loads parameters determined through measurements, Kromer R.K. calculated bed load discharge on the rivers Turgen, Esik and Kaskelen, according to the proposed technique, based on the stochastic approach to load transport and the method described in the work [Duskayev 1997, Mikhalev 2013, Matskina et. al. 2021].

The results of the calculations of bed load discharge, made in compliance with the proposed technique, are given in Table 1.

Then, for the same conditions, they calculated the values of bed load discharge, according to the formulas of different authors, and conducted a comparative analysis.

Besides, in line with the calculation technique proposed by the authors of the given work, they have made calculations of bottom sediment with the use of morphometric characteristics of channel and stream flow hydrograph for the stations of hydrological posts of Turgen River – Tauturen Settlement, Esik River – Esik Settlement, Kaskelen River – Kaskelen Settlement, the stations of the above-mentioned rivers are located upstream, higher than stations measured by Kromer R.K [Kromer 1985, Alimkulov et. al. 2021, Tursanova 2016]. The results of these calculations have later been compared to the data of the measurements performed on locations by Kromer R.K. Such measurements have been made for the purpose of adapting the technique in question to the data received by stationary observations made directly on hydrological posts.

Calculation of bed load discharge on the basis of different authors’ formulas was made in the following way.

The authors of this paper used the same morphometric channel data and hydraulic characteristics of the stream that were used in the measurements made by Kromer R.K., discharge value was calculated by substituting these characteristics in a relevant formula. All formulas were brought to a unified form for comparison purposes.

The formulas of the following authors were used for calculation of $P_{n1}$ value [Duskaev 1995, Duskayev et. al. 2020, Karaushev 1977]:
Table 1. The calculation of the bed load discharge, made in compliance with the proposed technique on the rivers of the northern slope of the Ile Alatau mountain.

<table>
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<th>River – Gauging Station</th>
<th>Q, m³/s</th>
<th>H, m</th>
<th>V, m/s</th>
<th>(d_{cr}, \text{m} )</th>
<th>I</th>
<th>(U^*, \text{m/s} )</th>
<th>(Re^* )</th>
<th>(Ar )</th>
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</table>

Goncharova V.N.

\[
P_{as} = 1.2(1 + \phi)V_u \cdot d \left( \frac{V_{cp}}{V_{nav}} \right)^{1.33} \quad (5)
\]

Shamova G.I.

\[
P_{as} = k \left( \frac{V_{cp}}{V_{nav}} \right)^3 (V_{cp} - V_{nav}) \left( \frac{d}{h} \right)^{0.25} \quad (6)
\]

Levi I.I.

\[
P_{as} = 0.002 \cdot \left( \frac{V_{cp}}{\sqrt{gd}} \right)^3 (V_{cp} - V_{nav}) \cdot \left( \frac{d}{h} \right)^{0.25} \quad (7)
\]

Dow-Go-Zhenya

\[
P_{as} = 0.048 \cdot d \cdot (V_{cp} - V_{nav}) \cdot \frac{\omega}{V_{nav}} \cdot \frac{V_{cp}}{V_{nav}} \quad (8)
\]

Grishanin K.V.

\[
P_{as} = 0.015 \left( \frac{V_{cp}}{V_{nav}} \right)^3 d (V_{cp} - V_{nav}) \quad (9)
\]

Egiazarov I.V.

\[
P_{aw} = 24q \sqrt{T \left[ \frac{RI}{1.6 f_s d} - 1 \right]} \quad (10)
\]

The following symbols are used here:

- \(\phi\) – an experimental parameter;
- \(V_{cp}\) – initial velocity of particles’ gravitational attraction, m/sec.;
- \(V_{ave}\) – average speed of a stream, m/sec.;
- \(d\) – particles sizes, meters;
- \(h\) – stream depth, meters;
- \(k\) – coefficient depending on bottom sediment;
- \(\omega\) – average absolute value of stream’s pulsating speed;
- \(R\) – hydraulic radius;
- \(I\) – inclination of water surface;
- \(q\) – elementary water expenditure;
- \(f_s\) – coefficient of resistance of movable bed or channel.

The results of the calculation of bed load discharge, based on the formulas of different authors,
The data consolidated in Table 2 testify to the fact that design formulas of practically all authors are characterized by considerable deviation from the measured $P_{\text{wL}}$ values.

### CONCLUSIONS

The proposed calculation technique gives quite satisfactory results compared to other design formulas used for determination of
bottom sediment. The calculated values of $P_{vl}$ often differ significantly from the measured values, though in some cases these values coincide. The causes of such deviations and coincidences of the calculated values of $P_{vl}$ and the measured values of bottom sediment discharge require detailed analysis and further check of measurements, based on the reliable data.

REFERENCES