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Calculation of Bed Load Discharge for Coarse Sand

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ABSTRACT

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.

Keywords: bed load discharge, hydrology, water bodies, fluvial processes.

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-fluvial deformations and fluvial-related processes in the case of water bodies and their separate sections.

According to the latest data provided by the specialists, only in the Russian Federation the annual damage caused by channel processes amounts to about 5 bln dollars. That is why the value or role of reliable forecasts of stream- fluvial deformations and fluvial-related processes is immeasurably high.

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 ($P_{вл.}$) 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 ($P_{вл.}$) 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.

$$P = A\left(\frac{\mathrm{Re}_*}{Ar^n}\right)^m \quad (1)$$

where:

$$\mathrm{Re} = \frac{U_* \cdot d}{\nu} \quad (2)$$

is Particle Reynolds number (characterizing a stream);

$$Ar = \frac{gd^3}{\nu^2}\left(\frac{\rho_{s-}\rho}{\rho}\right) \quad (3)$$

is Archimedean number (particles sizes);

$$Sh = \frac{U_* \cdot t}{d \cdot N} \quad (4)$$

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

Indication in dependences:

A, n, m – empirical coefficients;

U_* – 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;

ρ, ρ_s. – density of water and sediment;

υ – 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 – Tauturgen 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, Tursunova 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 $P_{\text{вл.}}$ 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

River – Gauging Station	Q, m³/s	H, m	V, m/s	d_{cp}, m	I	U*, m²/s	Re*	Ar	R_b, kg/s
Turgen intakes	13.5	0.58	1.66	0.033	0.0221	0.35	10264.9	447594837	0.66
	8.9	0.6	1.6	0.032	0.0227	0.37	10260.5	408124986	0.73
	9.2	0.57	2.05	0.041	0.0232	0.36	12953.7	858410100	0.18
	7.3	0.6	1.72	0.035	0.02	0.34	10533.9	534007531	0.17
	6.3	0.48	1.43	0.023	0.0228	0.33	6610.7	151539816	0.75
	6.2	0.47	1.45	0.026	0.0221	0.32	7280.3	218908837	0.32
	6.3	0.5	1.44	0.037	0.0231	0.34	10925.0	630882413	0.13
	6.6	0.43	1.55	0.032	0.0231	0.31	8762.3	408124986	0.11
	11	0.48	1.66	0.032	0.0221	0.32	9055.2	408124986	0.23
	6.6	0.57	1.54	0.037	0.0235	0.36	11765.3	630882413	0.29
	6.6	0.55	1.55	0.025	0.0231	0.35	7742.1	194609159	1.13
	9.6	0.52	1.53	0.037	0.023	0.34	11117.2	630882413	0.23
	8.1	0.49	1.64	0.033	0.0231	0.33	9646.0	447594837	0.22
Esik intakes	10.6	0.5	1.53	0.041	0.0177	0.29	10597.1	858410100	0.03
	9.8	0.53	1.87	0.032	0.0172	0.30	8394.2	408124986	0.06
	9.8	0.5	2.01	0.038	0.0183	0.30	9986.7	683430000	0.03
	9.8	0.5	1.75	0.035	0.0177	0.29	9046.3	534007531	0.04
	10.6	0.56	1.6	0.031	0.0179	0.31	8527.3	371046492	0.16
	11.7	0.49	1.43	0.037	0.0179	0.29	9520.4	630882413	0.05
	12.2	0.59	1.66	0.031	0.0179	0.32	8752.7	371046492	0.23
	15.1	0.64	2.08	0.034	0.0183	0.34	10109.4	489530776	0.27
	15.3	0.65	1.91	0.044	0.0179	0.34	13039.6	1060965540	0.09
	15.5	0.68	2.07	0.04	0.0166	0.33	11676.1	797119114	0.10
Kaskelen intakes	9.1	0.56	1.52	0.033	0.019	0.32	9352.2	447594837	0.16

Goncharova V.N.

$$P_{вл} = 1.2(1+\varphi)V_{н} \cdot d\left(\frac{V_{CP}}{V_{нач}}\right)^{4.33} \qquad (5)$$

Shamova G.I.

$$P_{вл} = k\left(\frac{V_{cp}}{V_{нач}}\right)^{3}\left(V_{cp} - V_{нач}\right)\cdot\left(\frac{d}{h}\right)^{0.25} \qquad (6)$$

Levi I.I.

$$P_{вл} = 0.002 \cdot \left(\frac{V_{cp}}{\sqrt{gd}}\right)^{3}\left(V_{cp} - V_{нач}\right)\cdot\left(\frac{d}{h}\right)^{0.25} \qquad (7)$$

Dow-Go-Zhenya

$$P_{вл} = 0.048 \cdot d \cdot \left(V_{cp} - V_{нач}\right)\cdot\frac{\omega}{V_{нач}}\cdot\frac{V_{cp}^{\;2}}{V_{нач}} \qquad (8)$$

Grishanin K.V.

$$P_{вл} = 0.015\left(\frac{V_{cp}}{V_{нач}}\right)^{3} d\left(V_{cp} - V_{нач}\right) \qquad (9)$$

Egiazarov I.V.

$$P_{\hat{a}\ddot{e}} = 24q\sqrt{I}\left[\frac{RI}{1{,}6 f_0 d} - 1\right] \qquad (10)$$

The following symbols are used here:
φ – an experimental parameter;
$V_{нач}$ – initial velocity of particles' gravitational attraction, m/sec.;
V_{cp} – average speed of a stream, m/sec.;
d – particles sizes, meters;
h – stream depth, meters;
k – coefficient depending on bottom sediment;
ω – average absolute value of stream' s pulsating speed;
R – hydraulic radius;
I – inclination of water surface;
q – elementary water expenditure;
f_o – coefficient of resistance of movable bed or channel .

The results of the calculation of bed load discharge, based on the formulas of different authors,

Table 2. Calculation data of the bed load discharge on the rivers of the northern slope of the Ile Alatau mountain

River - Post	Data	Q, m³/s	d, m	Kromer		Bed load discharge, кг/с						
				Specific bed load discharge $q_н$, kg/s·m	Bed load discharge, kg/s	By the proposed procedure	Egiazarov I.V.	Shamova G.I.	Goncharova V.N.	Levi I.I.	Grishanin K.V.	Dow-Go-Zhenya
Turgen intakes	21.08.1976	13.5	0.033	0.031	0.43	0.66	0.036	0.046	0.007	0.00024	0.00027	0.00013
	23.08.1976	8.9	0.032	0.114	1.06	0.73	0.025	0.033	0.004	0.00018	0.00019	0.00008
	24.08.1976	9.2	0.041	0.027	0.21	0.18	0.016	0.165	0.038	0.00085	0.001	0.00044
	25.08.1976	7.3	0.035	0.213	1.5	0.17	0.016	0.053	0.009	0.00028	0.00032	0.00014
	26.08.1976	6.3	0.023	0.098	0.9	0.75	0.03	0.032	0.004	0.00015	0.00016	0.00006
	27.08.1976	6.2	0.026	0.019	0.17	0.32	0.024	0.03	0.004	0.00014	0.00016	0.00006
	30.08.1976	6.3	0.037	0.121	1.06	0.13	0.014	0.007	0.0003	0.00003	0.00004	0.00001
	31.08.1976	6.6	0.032	0.0159	0.16	0.11	0.019	0.043	0.006	0.00019	0.00023	0.0001
	01.09.1976	11	0.032	0.021	0.29	0.23	0.031	0.063	0.011	0.0003	0.00035	0.00014
	02.09.1976	6.6	0.037	0.092	0.69	0.29	0.014	0.016	0.001	0.00008	0.0001	0.00004
	03.09.1976	6.6	0.025	0.053	0.41	1.13	0.028	0.044	0.007	0.00023	0.00024	0.00008
	06.09.1976	9.6	0.037	0.23	2.78	0.23	0.021	0.018	0.002	0.00009	0.00011	0.00004
	07.09.1976	8.1	0.033	0.004	0.04	0.22	0.022	0.053	0.008	0.00026	0.0003	0.00015
Turgen intakes	04.08.1976	10.6	0.041	0.035	0.48	0.026	0.016	0.013	0.001	0.00006	0.00008	0.00003
	06.08.1976	9.8	0.032	0.037	0.37	0.063	0.024	0.13	0.027	0.00064	0.00073	0.00028
	09.08.1976	9.8	0.038	0.018	0.18	0.031	0.018	0.18	0.042	0.00088	0.00107	0.00045
	10.08.1976	9.8	0.035	0.204	2.28	0.041	0.021	0.079	0.014	0.00038	0.00045	0.0002
	11.08.1976	10.6	0.031	0.074	0.88	0.157	0.028	0.039	0.006	0.0002	0.00023	0.00009
	12.08.1976	11.7	0.037	0.035	0.58	0.045	0.022	0.006	0.0002	0.00003	0.00004	0.00002
	13.08.1976	12.2	0.031	0.067	0.83	0.230	0.032	0.05	0.008	0.00026	0.00029	0.0001
	14.08.1976	15.1	0.034	0.013	0.15	0.270	0.034	0.19	0.047	0.00104	0.00115	0.00043
	16.08.1976	15.3	0.044	0.053	0.65	0.094	0.020	0.077	0.014	0.00042	0.0005	0.0002
	17.08.1976	15.5	0.04	0.122	1.34	0.104	0.024	0.15	0.034	0.00083	0.00094	0.00039
Kaskelen intakes	06.07.1976	9.1	0.033	0.008	0.09	0.16	0.022	0.02	0.002	0.0001	0.00012	0.00006

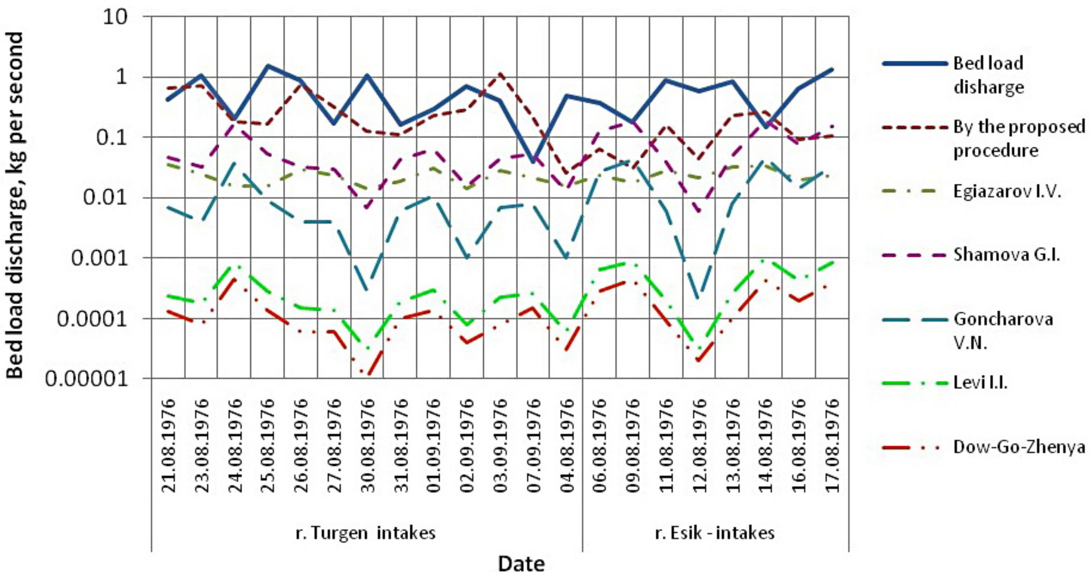

Figure 1. Graphical illustration of the different methods of calculating bed load discharge showing the proposed technique

are given in Table 2 and illustrated in Figure 1. 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 $P_{вл.}$ 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 $P_{вл.}$ 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 $P_{вл.}$ and the measured values of bottom sediment discharge require detailed analysis and further check of measurements, based on the reliable data.

REFERENCES

1. Duskaev, K.K. 1997. Стохастический метод расчета расхода влекомых наносов на горных реках. Вестник КазГУ. Серия географическая, (4), 77–79. (in Russian)
2. Duskaev, K.K. 1995, Principles of stone stabiity and the Probability of Armour Layer Break in Riprap Structures. River, Coastal and Shoreline Protestion. John Willey and Sons, Chichester, England, 677–682.
3. Mikhalev, M.A., Duskaev, K.K. 1992, Determination of the stability of stones on a slope with a given probability of detachment. Hydrotechnical Construction, 174–178.
4. Mikhalev, M.A., Duskaev, K.K. 1988, Determination of the stability of stones on a slope with a given probability of detachment. Hydrotechnical Construction, 22(3), 174–178
5. Mikhalev, M.A. 1975, Materials on modeling some types of motion of a viscous fluid. Izvestia Vedeneeva VNIIG, Leningrad, 108, 27–39. (in Russian)
6. Mikhalev, M.A. 2013, Calculating the main canals. Magazine of Civil Engineering, 39(4), 83–93
7. Matskina, M.M., Petrochenko, M.V., Radaev, A.E. 2021, Stochastic model of the construction process implemented with application of sliding formwork. Magazine of Civil Engineering, 101(1), 10111.
8. Veksler, A.B., Petrov, O.A. 2020, Calculated Relationship Between Flow Rates and Water Levels in the Downstream Pools of Hydroelectric Power Plants as a Result of River-Bed Transformation. Power Technology and Engineering, 53(6), 695–702.
9. Tursunova, A., Kunshygar, D.Z. 2016 Self-purification ability of ponds of Kazakhstan. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2(416), 87–92.
10. Alimkulov, S.K., Saparova, A.A., Tursunova, A.A., Baspakova, G.R. 2021 Measuring spatial-temporal regularities of river flow based on IoT technology. International Journal of Agricultural Resources, Governance and Ecology, 17(2–4), 247–261.
11. Duskayev, K.K. 1988. Calculation of bank protection from rockfill, taking into account the probability of stone failure. Proceedings of the 5th All-Union Hydrological Congress, V.10, Book 2. Gidrometeoizdat, Leningrad, 260–266. (in Russian)
12. Kromer, R.K. 1985. The regime of solid runoff of the rivers of the South of Kazakhstan. Water Resources, 6, 105–110. (in Russian)
13. Duskayev, K., Myrzakhmetov, A., Zhanabayeva, Z., Klein, I. 2020. Features of the sediment runoff regime downstream the Ile river. Journal of Ecological Engineering, 21(2), 117–125.
14. Karaushev A. 1977. Theory and methods applied in estimation of river drifts. Gidrometeoizdat, Leningrad, 272. (in Russian)