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DRIFT FLOWING OF THE RIVER TOM (THE WESTERN SIBERIA)

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The results of studying the flow of tractional and suspended sediments of the river Tom near the city Tomsk have been presented. It is shown that it is preferable to apply G.I. Shamov's method to determine the losses of tractional particles. It is stated that average total solid drift near Tomsk (undercurrent of the Tom) amounted 47,89 kg/day or 1510179 t/year within 1986–2005. Its bulk includes suspended particles (65,4 %). Average flow of tractional drifts amounted 16,57 kg/day or 522519 t/year. The recommendations on bed-correcting are given.

Introduction

Definition of the river sediment flow is the most complicated scientific problem considered in order to solve a number of fundamental and applied water problems, connected with studying of mass- and energostreams in biosphere, estimation and forecasting of water objects condition, prevention of water negative influence and development mineral deposits. The flow of river sediments consists of suspended (transferred throughout all strata of the stream) and tractional (transferred in the benthonic layer of the stream) particles. The first component of the drain can be rather simply measured, but essential scientific, methodical and technical difficulties arise at definition of the second component. As consequence, there is no authentic data about the flow of tractional and total sediments in many rivers including the river Tom – one of the largest inflows of the river Ob. It essentially complicates acceptance of administrative decisions in the field of forecasting and prevention of water negative influence in the lowest current of this water-current.

The norm for water flow of the river Tom in the Tomsk area makes 1031 m^3/s. Its biggest part (69 %) is during the period of spring high water (April – June). Before 1960, clogging and damming phenomena and connected with them flooding of the Tomsk territory and neighboring villages were often cited [1]. From 1950^{th} up to the middle of 1980, an intensive extraction of sand-gravel material (SGM) was carried out directly in the river channel. Based on the opinion of a number of authors it was the reason of floor reduction by 2,5 m, and, as consequence, water level reduction [2–4]. At the same time, the outline change of coastal line and fluvial formations occurred. Many islands and oseredok either disappeared, or changed in its form and decreased in their areas as a result. Approximately during the same time (from 1950 up to the middle of 1980) spring high waters cease to represent a threat for Tomsk city regarding its flooding. In the middle of 1980 works on fluvial SGM extraction near Tomsk city were curtailed, and in the end of 1990 an expansion of existing oseredok and their transformation into islands was marked in the river Tom in the area 73...70 km from the mouth. Based on such circumstances, strengthening of the channel washout and increase of maximum water levels occurred, which was not the case for about 40 years [5].

One of possible solutions regarding prevention of the lately revealed washout of the coast and hydraulic engineering constructions consists in increase of throughput ability of the river Tom channel within the limits of Tomsk city due to withdrawal of some fluvial alluvium and border maintenance of the low-flow channel on uniform distance from the coast. But the data on incoming to these site sediments is necessary for it. The volume of channel works should be designed based on this data, as well as the information on sediment flow within a year and in a long-term section. Such problem was set in the given work executed according to channel mapping OAO «Tomskgeomonitoring», of the Tomsk area of waterways and navigation and by the materials of hydrological observation of the Tomsk center on hydrometeorology and environment monitoring (TCHMandEM), of the Tomsk State (TSU) and Tomsk Polytechnic (TPU) universities for 1985–2005.

Technique of researches

The total flow of river sediments can be estimated on the basis of the channel deformation equation analysis, having the view:

$$\frac{\partial G_{вл}}{\partial x} - q_{взв} + m_0\, B\, \frac{\partial z}{\partial t} = 0, \qquad (1)$$

where $G_{вл}$ is the expenditure of tractional sediments in the volume of non-shallow rock; $q_{взв}$ is the expenditure of suspended sediments settling onto the floor or rising upwards; m_0 is the relative density of soils and sediments; B is the width of the river, m; x is the coordinate of longitudinal displacement; z is the high-altitude mark of the floor; t is the coordinate of time [6–8]. According to widespread in the Russian Federation assumption [8–12], the magnitude $q_{взв}$ can be calculated by the A.V. Karaushev's method:

$$q_{взв}=(u+k_u)\,S_{end.}-k_u\,S_{wash.},$$

where u is the hydraulic size of sediments, m/s; S_{wash} is the washout turbidity, calculated for the element of transit jet, g/m^3; S_{end} is the average turbidity of water at the end of the element Δx, g/m^3; k_u is the coefficient defined from the condition of channel balance:

$$k_u = \frac{u\,\Gamma}{1-\Gamma},$$

where H is the hydromechanical parameter of sediments calculated for the *i-th* fraction of sediments depending on functions $B_i\,(u_i/v;\,C_{sh})$ and $F_i\,(u_i/v_z)$ under the formula:

$$H_i = B_i \cdot F_i,$$

functions B_i and F_i are defined by interpolation under corresponding schedules from the work [8] depending on hydraulic size of sediments u, vertical pulsations v_z, average flow velocity v- and values of Shesi C_{sh} coefficient.

Washout turbidity S_{wash} (in g/m^3) can be calculated under the formula:

$$S_{взм.} = 150\, a\, N\, \eta^2 \frac{\overline{v}^2}{\overline{h}},$$

$$N = \frac{M\, C_ш}{g},$$

$$M = \begin{cases} 0,7\, C_ш + 6 & \text{at } 10 \le C_ш \le 60 \\ 48 & \text{at } C_ш > 60 \end{cases},$$

where $\overline{h}$ is the average depth of the watercourse, m; a is the correction coefficient defined from a parity of average measured turbidity $S_{av.meas.}$ and designed transporting ability of the stream $S_{tr.}$ ($a=S_{av.meas.}/S_{tr.}$); g is the acceleration of free falling, m^2/s; η is the transition from average speed of the stream to the floor speed, calculated under the formula:

$$\eta^2 = \frac{0,53\, C_ш - 4,1}{C_ш - 2}.$$

Transporting ability of the stream $S_{tr.}$ (g/m^3) is calculated under the formula:

$$S_{tr.} = H \cdot S_{wash},$$

Water average turbidity S_{end} at the end of the element Δx is defined by the expression:

$$S_{кон.} = S_{тр} + (S_{нач} - S_{тр}) \exp\left(-\frac{B\,(u + k_u)}{Q} \Delta x \right),$$

where S_{beg} is the water average turbidity at the beginning of the element Δx, g/m^3; Q is the water expenditure, m^3/s.

The situation is less unequivocal in case of flow definition of tractional sediments. Dozens of ways are offered by various authors, and results of calculation can very much differ from one another [6, 13, 14]. Different questions may arise taking that into account, such as: What method should be used in case of the river Tom and how large is the expenditure of tractional sediments of the given watercourse?

The following algorithm has been used to answer the questions specified above.

1. Based on materials of channel mapping executed by the Tomsk site of waterways and navigation in 20.05.2001 and 23.05.2003, the digital model of the river Tom channel in the upper part of Tomsk city has been made.
2. Based on regime hydrometric observations of Federal Hydrometereology and Environmental Monitoring Service, obtained in hydrosolution 74 km from the river Tom mouth, the dependences between water expenditure Q, average depth of the watercourse $\overline{h}$, width of the channel B were revealed and values $\overline{h}$ and B for each day of the period from 20.05.2001 up to 23.05.2003 were calculated. Then the values of the live section area ω, average speed of the current $\overline{v}$, the Shesi's coefficient C_{sh}, roughness coefficient n adjusted for presence of an ice cover during the winter period, average diameter of floor deposit particles under the Shtrikler's formula and diameter boundary values of floor deposits and tractional sediments, tractional and suspended sediments according to [10, 12] were calculated. The parity between average diameter of particles and diameter of particles with various security is accepted according to the data resulted in work [15].
3. Value q_{susp} and expenditures of tractional sediments in valves 72 km from the mouth were measured based on calculated stream characteristics. The following methods of their definition were used.

3.1. The I.I. Levi's method. According to [6, 11], calculation of value G_{tr} for rivers, where sediments are presented by sand and gravel is necessary to conduct under the formula:

$$G_{вл(Л)} = 0,002\, B\, \overline{d}\, (\overline{v} - v_{нл}) \left(\frac{\overline{v}}{\sqrt{g\, \overline{d}}} \right)^3 \left(\frac{\overline{d}}{\overline{h}} \right)^{\frac{1}{4}},$$

where $G_{вл(Л)}$ is $G_{tr(L)}$, $\overline{d}$ is the average diameter of sediments, m; v_{nv} ($v_{нл}$) is the noneroding velocity (by I.I. Levi), defined according to [11].

3.2. The G.I. Shamov's method. According to [8, 10, 16], expenditure calculation of tractional sediments at sandy and sandy-gravel composition of floor deposits is recommended to carry out under the G.I. Shamov's formula:

$$G_{вл(Ш)} = k\, B \left(\frac{\overline{v}}{v_{нш}} \right)^3 (\overline{v} - v_{нш}) \left(\frac{\overline{d}}{\overline{h}} \right)^{\frac{1}{4}},$$

where $G_{вл(Sh)}$ is $G_{tr(Sh)}$, k is the coefficient considering composition heterogeneity of tractional sediments (for homogeneous composition of sediments k=0,95$\sqrt{d}$); parameter $v_{нш}$ is the defined according to [10].

3.3. The V.N. Goncharov's method. It is shown by V.N. Goncharov that for sediments with a diameter from 0,2 up to 10 mm it is expedient to apply the settlement formula:

$$G_{вл(G)} = 1,2\,(1+\psi)\, \overline{d}\, v_{нв} \left(\frac{\overline{v}}{v_{нг}} \right)^{4,33},$$

where $G_{вл(G)}$ is $G_{tr(G)}$, parameters ψ and $v_{нг}$ are defined according to [7].

3.4. The K.I. Rossinskiy's method. According to [10], for expenditure calculation of tractional sediments at gravel-pebble composition of floor deposits it is recommended to use the formula:

$$G_{вл(P)} = 0,2\, \rho_н\, \overline{d}\, k_p\, \overline{v}\, B \left(\begin{array}{l} \varphi - \dfrac{7,7\sqrt{\overline{d}}}{k_p\, \overline{v}} (\varphi - \varphi_в) + \\ +0,4\,\theta \exp\left(-\dfrac{1}{2\,\theta^2} \left(\dfrac{7,7\sqrt{\overline{d}}}{k_p\, \overline{v}} - 1 \right)^2 \right) \end{array} \right),$$

where $G_{вл(R)}$ is $G_{tr(R)}$, coefficient k_p is defined under special schedules depending on floor relative roughness, and coefficients φ and $\varphi_в$ depending on values

$$x = \frac{1}{\theta}\left(\frac{7,7\sqrt{\bar{d}}}{k_p\ \bar{v}} - 1\right) \text{ and } x_в = \frac{1}{\theta}\left(\frac{10,8\sqrt{\bar{d}}}{k_p\ \bar{v}} - 1\right) [10].$$

4. Calculation of floor deformations Δz was carried out based on values q_{susp} and G_{tr} on average for rated valve under the equation (1). The mark of the bottom in each rated point z_i for every day of the rated period (i=1,...,L) was calculated; the distance between rated points is 100 m.
5. Deviation characteristics of the calculated values of floor marks from measured in each design point of the valve 72 km from the mouth, based on condition on 23.05.2003, were defined under the formulas:

$$\delta_1 = \frac{\sum (z_{\phi,i} - z_{p,i})}{L}, \quad (2)$$

where L is the quantity of compared points; $z_ф$ and z_p are actual and design marks of the river Tom floor in at the valve 72 km from the mouth.

$$\delta_2 = \sqrt{\frac{\sum (z_{\phi,i} - z_{p,i})^2}{L}}. \quad (3)$$

6. At final stage the analysis of obtained results with method choice was performed. The smallest values δ_1 and δ_2 are characteristic to the analyses. The flow of tractional sediments was calculated for the period of 1986–2005. The choice of this particular period can be explained that in the middle of 1980 extraction of SGM has been stopped in the river Tom Tomsk city, and dependences $\bar{h}=\bar{h}(Q)$ and $B=B(Q)$ have not essentially changed during this time [5].

Results of researches and their discussion

The best convergence of calculated and measured marks of the river Tom floor has been reached with G.I. Shamov's method used for calculation of tractional sediment flow. It allows recommending it for calculation of tractional sediment flow of the considered river. Similar results were also obtained under I.I. Levi and K.I. Rossinskiy formulas, but in the first case a bigger error at calculation of total expenditures of suspended and tractional sediments was noticed, and in the second – a greater error at calculation of total expenditures of suspended and tractional sediments (table).

With respect to the obtained data, a total flow of suspended and tractional sediments on average for 1986–2005 for the river Tom in hydrovalve of Tomsk city is estimated at the rate of 1510179±55630 t/year or 47,89±1,76 kg/s. The most part of firm flow is presented by suspended sediments (987660±50752 t/year or 31,32±1,61 kg/s). Their biggest contribution to formation of flow expenditures (more than 75 %) is dated to the period of spring high water. The average annual flow of tractional sediments makes 522519±7772 t/year or 16,57±0,25 kg/s.

Table. *Average arithmetic (δ_1) and average quadratic (δ_2) discrepancies* of design values from the actual, the average expenditure of the river Tom sediments (Tomsk) for the period between 20.05.2001 and 23.05.2003*

№	Valve	δ_1, m	δ_2, m	Average sediment expenditure, kg/s
1	Calculation of suspended sediments only by A.V. Karaushev	–0,70	0,93	34,26
2	Calculation of tractional sediments by G.I. Shamov	0,18	0,56	18,91
3	Calculation of tractional sediments only by I.I. Levi	0,18	0,56	14,52
4	Calculation of tractional sediments only by V.N. Goncharov	0,19	0,56	55,61
5	Calculation of tractional sediments only by K.I. Rossinskiy	0,19	0,56	21,02
6	Total calculation of tractional and suspended sediments by A.V. Karaushev and G.I. Shamov methods	–0,69	0,93	53,17
7	Total calculation of tractional and suspended sediments by A.V. Karaushev and I.I. Levi methods	–0,70	0,94	48,78
8	Total calculation of tractional and suspended sediments by A.V. Karaushev and V.N. Goncharov methods	–0,70	0,94	89,87
9	Total calculation of tractional and suspended sediments by A.V. Karaushev and K.I. Rossinskiy methods	–0,69	0,93	55,28

Note: values δ_1 are calculated under the formula (2), values δ_2 under the formula (3).

For intraannual distribution of firm drain (on average for the years 1986–2005) an essential variability is characteristic – from 0,74 kg/s in January up to 272 kg/s. The total sediment flow for spring high water (April – June) makes 82,5 % of an annual from, while in winter low water (December – March) only 0,6 %. In a long-term cut the total firm flow and correlation of tractional and suspended sediments essentially vary (Figure 1). Changes of these parameters in time in some cases are ambiguously connected with fluctuations of water flow (Figure 2).

It can be explained that at water content increase a disproportionate value change occurs in value coefficients of roughness, diameter of river sediments, depths and flow velocity (considering the given circumstance, and also labor input to calculate the total flow of deposits by the methods specified above), the search of more simple dependences between the total expenditure of sediments $G_н$ and hydraulic characteristics of the river has been executed.

Massif regression analysis of average daily values of water expenditure Q (m^3/s), total expenditures of suspended and tractional sediments $G_н$ (kg/s), coefficients of roughness n and average depths $\bar{h}$ (m) of the river Tom in Tomsk city hydrovalve during May-October, 1986–2005 allowed obtaining the expression (4) which lets us to define with an admissible error (the square of correlation attitude R^2 makes 0,70) to define average daily value $G_н$ for the investigated water-current during the time of open channel and suitable to carry out hydrological calculations of not only for the site within the limits of Tomsk city, but for low current of the river Tom as a whole.

Fig. 1. *Changes of average annual expenditures of tractional (I) and total (II) sediments of the river Tom near Tomsk city during the years 1986–2005*

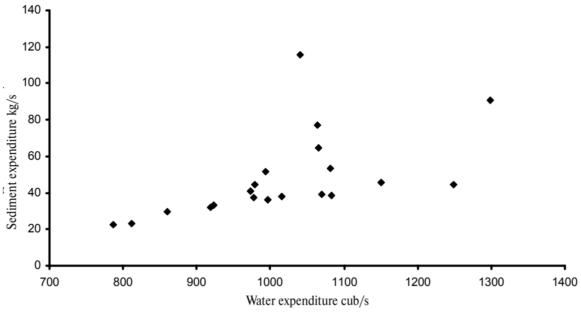

Fig. 2. *Dependence between the total expenditure of sediments and expenditure of the river Tom near Tomsk city*

$$G_и = Q\left(0{,}0187 + 0{,}00021\,\frac{\bar{h}^{-\frac{2}{3}}}{n}\right). \quad (4)$$

In particular, at the dependence (4) use for calculation of the total sediment expenditure 72 km from the mouth of the river Tom the R^2 amounted to 0,80.

Conclusion

As a result of the data analysis of the given long-term hydrological surveys and mathematical modeling of mouth deformations it is established that for expenditure calculation of tractional sediments of the river Tom is most expedient to use the G.I. Gamov's method. The total flow of suspended and tractional sediments of the specified river in hydrovalve of Tomsk city, calculated under A.V. Karakushev and G.I. Gamov methods, on average for the years 1986–2005 makes 1510179±55630 t/year or 47,89±1,76 kg/s, including the flow of tractional sediments representing greatest interest from the point of view of formation of sand-gravel material stocks, – 522519 t/year or 16,57 kg/s. It is obvious, that at withdrawal of sand-gravel materials within the limits of Tomsk city at a rate exceeding an error of definition of flow tractional sediments (i. e. 7772 t/year), statistically significant changes of river channel are probable. In view of it, extraction of the most quantity of sand-gravel materials from channel of the river Tom can be carried out only under condition of the special substantiation of such works including long-term forecast of mouth deformations and preparation of actions on protection of river coasts and hydraulic engineering constructions. The rough estimation of short-term changes of sediment expenditure and, hence, channel deformations, can be executed by means of the established empirical dependence.

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