

Evaluation of plain river channel deformation in the absence of observation data

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Abstract. Evaluation and long-term forecast techniques for plain river channel deformation has been developed in the absence of observation data. Their testing was performed by the example of medium rivers (with catchment area from 2000 to 50000 km²) in taiga zone of Western Siberia (the Ob river basin on the section of its midstream). The technique is based on determination of flow parameters, at which the maximum river bed deformations are observed. Standard data of hydrometric observations obtained at the state hydrological network are used for calculation.

1. Introduction

For design of water facilities, bridge and pipeline river crossing one needs to evaluate the value of horizontal and vertical river bed deformations [1–4]. Usually this problem is solved on the basis of river bed maps and schemes constructed in different years with the interval of not less than 5 years [3, 4]. The essence of the technique is comparison of cross-sections obtained as a result of channel survey in different years. Among its disadvantages are: high labour consumption of engineering-hydrometeorological survey and complexity or impossibility to obtain calculated parameters in a short time specified for design and survey by a customer; the technique is not applicable without reliable river bed survey made in different years with the interval of not less than 5 years; besides, even if time different river bed survey available, the comparison process of several views and schemes presents some additional errors and is not enough formalized.

In the absence of observation data there is a technique of line construction of possible vertical river bed erosion under the condition of deformations due to river bed ridge transformations [3, 4]. The essence of the technique consists in evaluation of vertical deformations in terms of relationships between microform bed sizes and flow depth [5]. Its disadvantages: it is applicable in the condition of ridgy sediment movement and does not permit reliable forecast for vertical deformations of a peat bed or a bed with insignificant load transport in the form of ridges; one needs measurements of flow parameters and bed shapes in the free channel period as most of small streams can freeze through in winter.

Limited possible horizontal river bed deformations (the profile length of limited scour L_{lim}) without observation data can be roughly defined according to [4] in the following way: 1) the type of bed process is stated on the researched river section and the width of flood plain flow is calculated $B_{FP,x}$; 2) using reference data [4] for a stated bed process the ratio of channel-forming belt width $B_{CT,a}$ and flood plain flow width $B_{FP,a}$ is taken, as well as mean square deviation of the ratio $\sigma_{CT,a}$; 3) the profile length of limited scour is taken as the product of flood plain flow width on the researched river section



$B_{FP,x}$ by the value $(B_{CT,a}/B_{FP,a} + \sigma_{CT,a})$ set for a stated bed process type. The technique allows reliable data on limited possible horizontal deformations, but without time reference (that limits the possibility of long-term forecast).

It is also known another forecast technique for river bed horizontal deformation in the absence of observation data based on the data on bed deformation of analogue river [3, 4]. It is based on data transition obtained by the techniques mentioned above for analogue river to the studied river taking into account forecast errors. The technique disadvantages: it is slightly suitable for hydrologically poorly studied areas of Siberia, where studied analogue rivers are few and presented mainly by large rivers with catchment area more than 50000 km²; taking this fact into account it is particularly difficult or impossible to match an analogue for an uninvestigated small river with catchment area less than 2000 km² (river classification according to [6]).

At present, horizontal bed deformation determination without observation data is mostly performed at qualitative level taking into account bed type and/or bed process, or by means of empirical formulas based, as a rule, on criterion relationships of scour diameter, flow depth, water surface slope and other parameters [1, 7–9].

The general disadvantages of existing techniques relevant for the river bed forecast deformation are as follows: 1) most of existing methods need time different bed survey with the interval not less than 5 years on studied river or analogue river; 2) in the design of construction projects on hard access areas of Siberian taiga, tundra forest, and tundra zones the bed survey data in different years (particularly with the interval of less than 5 years) are usually absent or do not meet the requirements in accuracy specified in [3]; 3) labour consumption of engineering-hydrometeorological surveys, complexity or impossibility of obtaining calculation parameter in short terms defined for surveys and design; 4) high degree of inaccuracy in measurement and calculation of parameters used for indirect evaluation and forecast of planned (horizontal) river bed deformations; 5) significant deviations of calculated bed deformation values from measured values, if a technique is used in other region in the conditions different from those considered in development of this or that technique (for example, in case of muskeg banks).

Keeping these in mind the authors have performed the research in bed deformation of plain rivers to develop technique for obtaining their quantitative characteristics in the absence or minimum of observation material. Technique testing was made in terms of data obtained at state observation network of the Russian Federal Service in Hydrometeorology and Environmental Monitoring (Roshydromet) and the regional network of JSCo «Tomskgeomonitoring» (Tomsk) on the rivers of taiga zone in the basin of the Ob River (Western Siberia).

2. Description of the studied area

The area involved corresponds to the administrative borders of Tomsk Oblast. It is located in the Central and South-Eastern parts of West Siberian Plain and characterized by predominance of two differently directed groups of exogenous geologic processes – swamp and bed processes. The first group deals with accumulation of organic matter at catchment, decrease in river load flow and definite increase in ground elevations due to peat deposit formation at the stage of oligotrophic domed bogs, whereas the second – on the contrary, high relief roughness and increase in solid flow. The mentioned above processes are closely interconnected over the period of all Holocene, water flow was directed in accordance with different hypothesis: 1) The Arctic Ocean between open tongues of Ural and Siberian glaciers, or in the absence of land glaciation, or between different time Ural and Siberian glaciers, or through glacier (including under glacier); 2) in Aral-Caspian basin through Turgai depression; 3) in blind West-Siberian basin (sea) [10].

Being uninvolved in discussion we would like to note that, anyway, one of the reasons for West-Siberian Plain bog formation (that reaches 30 % of the territory and more [11–13]) could be continuous transformations of river beds in easily eroded soils in the absence of tree vegetation and excessive moisturizing of catchments as a result of deglaciation, precipitation, and difficulty in water flow from the area involved. In such conditions existence of numerous dead channels became a

catalyst of area bog formation in some cases, moreover, eutrophication of inundated reservoirs is going on now. The analysis of engineering survey materials permitted us to make conclusion on the fact that bed process contributed to bog formation on a regional scale that, thereafter, resulted in some bed deformation stabilization, at least, of small rivers. The next stage of bog formation process became development of secondary river network of bog streams and reservoirs in the condition of excessive or moderate moistening and deteriorating conditions of water runoff, in some cases stream bog beds form at watersheds of disappeared synantetic rivers [14, 15].

Virtually, the Ob River within Tomsk Oblast borders is characterized by prevailing development of bed braidedness, in the central and northern part – by incomplete meandering and flood plain braidedness. The downstream of the Tom River is distinguished by incomplete meandering, bed and flood plain meandering, in some places limited meandering. On the Chulym River and its tributaries within Tomsk Oblast the free and incomplete meandering, bed braidedness prevails. The other medium rivers of the area involved are characterized by incomplete meandering. The rest types of bed process in terms of the State Hydrological Institute classification [3] are generally absent or conditioned by the local sections of some rivers [14]. The general characteristic of horizontal deformation of some largest regional rivers obtained in terms of observation data by JSCo «Tomskgeomonitoring» within 1996–2005 is presented in table 1.

Table 1. Characteristic of river bank erosion of Tomsk Oblast [14], m/year.

Settlement	River	Eroding velocity	
		mean	maximum
Kolpashevo	Ob	4.4	15.0
Krivosheino	–//–	0.7	20.0
Zyraynskoye	Chulym	4.9	30.0
Komsomol'sk	–//–	10.8	22.0
Podgornoye	Chaya	1.6	30.0
Moryakovka	Tom	4.4	20.5

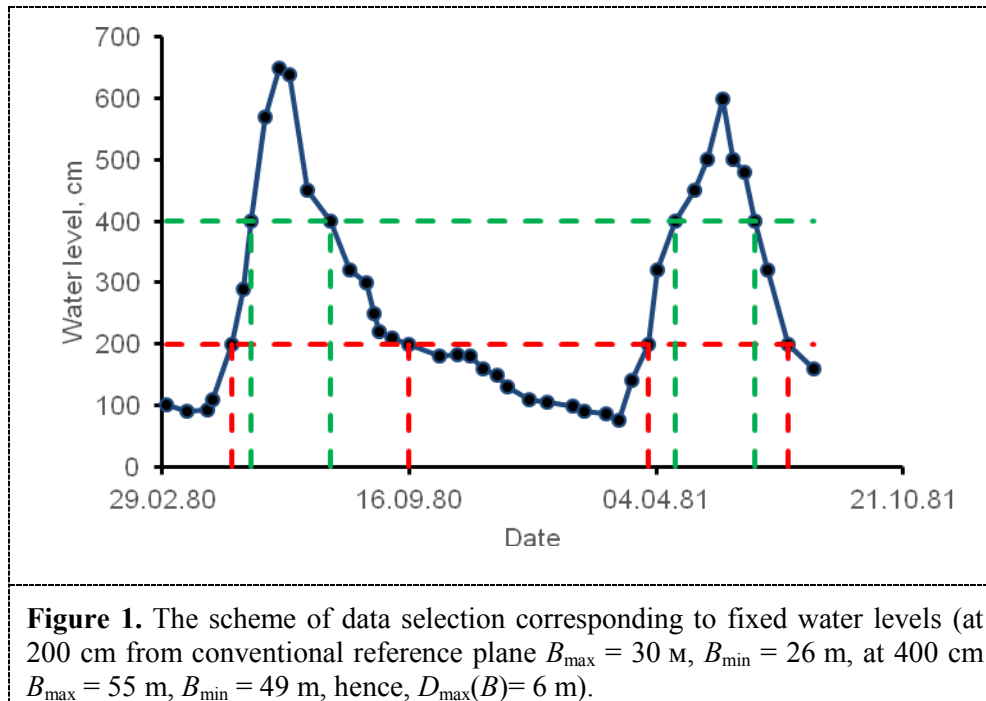
3. Results and discussion

The program of standard hydrometric observations at the state monitoring network over the territory of the Russian Federation (at flow points) includes everyday measurement of water levels (twice and more) and measurement of stream velocity, stream depth and width, as a rule, not less than once a month. In some cases hydrometric operations have been performed since the 1930's, more often – since the 1950-1960's. Owing to the operations there are sufficiently long rows of observations of water levels, stream width, its mean and maximum depth.

Based on the results of the data analysis an approach to bed deformation evaluation (both horizontal and vertical) is introduced, it involves determination of flow parameters, at which maximum bed deformation is observed. The approach consists in selection of observation data corresponding to the fixed water level (in Baltic elevation system) set with some constant increment from the observed (or calculated) minimum to the relevant maximum. The example of data selection for fixed water levels (200 and 400 cm from conventional reference plane) is shown in figure 1.

In case when just such a value of water level is absent in data, it is to be found by interpolation between the next following dates. In the resultant selection there has to be an even number of selected levels corresponding both to river water rise and fall. For each data selection, at fixed water level the minimal and maximal values of the sought quantity (width, mean and maximum stream depth) is defined and its maximum oscillating amplitude (the difference between maximum and minimum) is calculated. The maximum amplitude value for the whole studied range of level water changes is a characteristic of vertical $D_{\max}(h_{\max})$ (in case of maximum stream depth h_{\max}) or scheduled $D_{\max}(B)$ (for stream width B) of river bed deformation. It should be noted that channel control is usually fixed at the least deformed and straightest river section. Taking this into account the resultant values of river bed deformation can be considered as maximums for the most stable sections that well corresponds to the

project tasks directed to searching for limited values of hydrological characteristics and bridge and pipeline crossing construction and other facilities in similar regions.



The testing results of the approach described concerning the data on medium rivers in taiga zone of West Siberia are presented in table 2. The analysis showed that, firstly, vertical deformations change in the range of 0.39–1.27 m, but scheduled ones – in the range of 4.55–16.01 m [16]. It corresponds to both the results of engineering survey on the area involved and (in case of vertical deformations) calculations of bottom deformations conditioned by bed shape transformations [16].

Table 2. Characteristic of water runoff and river bed deformations of plain tributaries of the Ob River in taiga zone.

River – settlement	Catchment area, km ²	Mean water discharge, m ³ /s	$D_{\max}(B)$, m	$D_{\max}(h_{\max})$, m
The River Chaya – Podgornoye	25000	78.7	9.98	1.27
The Parabel' River – Novikovo	17900	71.4	11.58	0.84
The Kenga River – Tsentral'ny	7440	24.5	13.28	0.39
The Vasyugan River – Sredniy Vasyugan	31700	162	8.22	0.89
The Vasyugan River – Maysk	3730	15.1	4.55	0.96
The Tym River – Vanzhil' – Kynak	10100	80.9	16.01	0.89

Note: characteristic of water runoff is given according to [14]

Secondly, between the indicated characteristics and difference of maximal and mean values of stream velocity and stream depth the statistically significant relationships were revealed. The physical sense of such relationships consists in consideration of: 1) solid flow as a magnitude proportional to flow energy losses at interaction with banks and bottom; 2) river bed deformation equation as a relationship between deformation in one of the directions (vertical or horizontal) and solid flow. The general view of the relationship:

$$D_x = k_1 \cdot (v_{\max} - v_a) \cdot d^{k_2}, \quad (1)$$

or

$$D_x = k_3 \cdot (h_{\max} - h_a) \cdot d^{k_2}, \quad (2)$$

where D_x – the characteristic of river bed deformation in x -direction (vertical or horizontal); v_{\max} and v_a – maximal and mean stream velocities; h_{\max} and h_a – maximal and mean stream depths; d – the typical load diameter; k_1, k_2, k_3 – empirical coefficients.

Thirdly, values of maximal change amplitude of stream width $D_{\max}(B)$ and maximal depth $D_{\max}(h_{\max})$ are on the whole comparable with corresponding evaluations of river bed deformations obtained by river bed survey and techniques based on calculation of river bed shape parameters and criteria of river bed stability [16].

In fact, evaluation of limited possible vertical bed scour Z_{\lim} and forecast of maximum possible scheduled bed deformations $\Delta B(T)$ of hydrologically uninvestigated plain rivers can be carried out using the formulas:

$$Z_{\lim} = Z_{\min} - D_{\max}(h_{\max}) - \delta_h, \quad (3)$$

$$\Delta B(T) = T \cdot (D_{\max}(B) + \delta_B), \quad (4)$$

where $\Delta B(T)$ – the forecast of scheduled river bed deformation in control point within the period T , m/period in years; δ_B and δ_h – errors in measurement of flow width and depth, m. Values of $D_{\max}(h_{\max})$ and $D_{\max}(B)$ are either taken in terms of data analysis of measured analogue river water discharges (for example, shown in Table 3) after preliminary grounding its choice, or calculated by empirical relationships using data on maximum and mean depths.

4. Conclusions

In the course of the given research the evaluation technique of river bed deformations for plain rivers is proposed and its testing in terms of medium rivers data in taiga zone of Western Siberia (the Ob River basin) is performed. The given technique allows the evaluation of vertical and horizontal river bed deformations of hydrologically uninvestigated plain rivers with permissible certainty. Undoubtedly, such evaluation cannot replace completely the results of relevant observations, but their application in other environmental conditions would require additional justification. Nevertheless, their application for this or that uninvestigated river in taiga zone, in Siberia in particular, could efficiently contribute to the analysis of several layout options for the designed facilities crossing a river and, consequently, sufficient cost reduction of engineering survey.

References

- [1] Chang H H 2008 *Fluvial Processes in River Engineering* (Malabar, Florida: Krieger publishing company) p 432
- [2] PNIIS Gosstroya SSSR 1987 *Rekomendatsii po otsenke i prognozu razmyva beregov ravninnykh rek i vodokhranilishch dlya stroitel'stva* (Moscow: Stroyizdat) p 72
- [3] VSN 163-83 *Vedomstvennye stroitel'nye normy. Uchet deformatsiy rechnykh rusel i beregov vodoyemov v zone perekhodov magistral'nykh trubuprovodov (neftegazoprovodov)* 1985 (Moscow: Goskomgidromet) p 142
- [4] GGI 2009 *Uchet ruslovogo protsessa na uchastkakh podvodnykh perekhodov truboprovodov cherez reki. Standard organizatsii. STO GU GGI 08.29-2009* (Saint-Petersburg: Nestor-Istoriya) p 184
- [5] Alexeevskiy N I 2006 *Gidrofizika* (Moscow: Academia) p 176
- [6] *Gidrologiya sushi Terminy i opredeleniya GOST 19179-73* 1988 (Moscow: Izdatil'stvo standartov) p 65
- [7] Leopold L B and Maddock T 1953 *The hydraulic geometry of stream channels and some physiographic implications* (United States Government Printing Office, Washington) p 57
- [8] Antropovskiy V I 1972 *Issledovaniya morfologii i gidravliki rechnykh rusel, poim i vodoyemov dlya nuzhd stroitel'nogo proyektirovaniya Trudy Gosudarstvennogo gidrologicheskogo instituta* **190** 5

- [9] Berkovich K. M., Zlotina I. B. 2003 Raschet stabil'nosti rechnykh rusel v usloviyakh antropogennoy nagruzki *Geography and Natural Resources* **2** 117
- [10] Maloletko A. M. 2008 *Evolutsiya rechnykh sistem Zapadnoy Sibiri v mezozoye i kaynozoye* – (Tomsk: TP Univesity Press) p 288
- [11] Neishtadt M. I. 1977 Vozniknoveniye i skorost' razvitiya protsessa zabolachivaniya *Nauchnye predposylki osvoeniya bolot Zapadnoy Sibiri* (Moscow: Nauka) pp 39–48
- [12] Bazanov V. A., Berezin A. E., Savichev O. G., Skugarev A. A. 2009 The phytoindication method for mapping peatlands in the taiga zone of the West-Siberian Plain *International Journal of Environmental Studies* vol 66 **4** 473
- [13] Eckstein Y., Savichev O. G., Pasechnik E. Y. 2014 Is climate change affecting ground water chemistry in the largest boreal wetland? *Geological Society of America. Annual Meeting in Vancouver, British Columbia* vol 46 **6** 67
- [14] Savichev O. G. 2010 *Vodnye resursy Tomskoy Oblasti* (Tomsk: TP Univesity Press) p 248
- [15] Savichev O. G., Paromov S. V. 2014 Hydrological aspects of bog formation in taiga zone of Western Siberia *Bulletin of the Tomsk Polytechnic University* V 324 **1** 154
- [16] Savichev O. G., Reshet'ko M. V. 2012 Estimating sediment yields and riverbed deformations of unexplored lowland rivers in the Western Siberia taiga zone *Engineering Surveys* **1** 52