Assessment of vertical channel deformations on the rivers of the Angara region based on hydrometric measurements data

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Abstract. The article presents the vertical channel deformations assessment (erosion of the riverbed bottom or accumulation of sediment) on the rivers of the Angara region. Channel processes are wide-spread here due to geomorphological and hydrological features of the territory. Vertical channel deformations are a change in the river bottom altitude under the water flow, sediment transport and accumulation. An important indicator of the dynamics of channel deformations is the changes of the water level and discharge. The Q = f (H) curve is one of the most important characteristics of the river’s water regime and bed morphometry. The direction and speed of the vertical channel deformations were determined by analysing the curves of the water level changes at a fixed discharge. The average of the annual maxima discharge is chosen as the fixed discharge. As a result, the sections of the rivers with erosion of the riverbed bottom, sections with a predominance of sediment accumulation, as well as stable sections of the riverbed have been identified. The identified trends of the vertical channel deformations were verified by constructing of cross-section channel profiles according to depth measurements for the period 1997-2017. Moreover, the imposition of multi-temporal cross-section channel profiles revealed not only vertical, but also horizontal deformations.

1. Introduction
Channel deformations can be dangerous for economic activity, for example, due to shallowing of water intakes and ship passages, destruction of hydraulic and linear structures, etc. This determines the relevance of research and the need for forecasting. In considering channel deformations, we distinguished horizontal (channel movements in plan) and vertical (changes in channel height) deformations.

The most serious difficulties arise with investigations into vertical deformations due to the lack and poor access of information. If for the study of planned deformations numerous and accessible materials of aerospace surveys can be used, then to identify vertical changes in the position of the channel, detailed field investigations or expensive laboratory modeling are required [1, 2]. This makes impossible regional studies of vertical deformations of channel networks to solve the problems of their zoning and identify patterns of spatial development. Therefore, the attention of researchers is aimed at finding possible sources of information about the processes under consideration and the development of methods for its interpretation [3, 4].

2. Objects, data and methods
The paper considers the possibility of using hydrometric measurements on the network of
Roshydromet gauging stations to get an idea of vertical deformations on discharge sites. Sources of information here are the results of measurements of water discharge, in particular:

- channel measurements of cross section during the year;
- distribution of hydraulic and morphometric characteristics of the flow along the width of the cross-section at the moments of measuring water discharge rates;
- the resulting characteristics of water discharge and its parameters of the entire flow.

For processing the abovementioned information and calculating the channel deformations, special software was developed [5] with the following objectives:

- to convert the hydrometric information of the Unified State Data Fund into common formats;
- to plot integrated sections according to measurements for any period of time and to calculate changes of the levels of the bed bottom;
- to plot dependences of the hydraulic-morphometric characteristics of the flow on the level for specified periods and to calculate vertical deformations on this basis.

We explored the use of hydrometric data for estimating vertical deformations for gauging stations within the Angara river catchment area, where hydrometric information was available for the authors for the period of 1997-2017. Let us consider some of the methods used to determine vertical deformations as exemplified by the Olkha river near the Olkha village with a catchment area of 590 km².

Comparison of changes in flow depth on separate verticals in time, i.e. comparison of bottom profiles, provides direct understanding of vertical deformations. We made measurements at different levels; they were reduced to the same height system as follows:

\[ h_d = H_0 + H - h_p \]  

where \( h_d \) is the absolute bottom mark, \( H_0 \) is level of zero of gauge, \( H \) is water level at the time of the measurements, \( h_p \) is the measured depth of the flow.

3. Results and discussion

Figure 1 shows the changes in time of the bottom marks on one of the verticals in the center of the channel. Despite the obvious tendency to deepen the bottom of the river, poorly explained high-frequency oscillations of the bed marks are visible.

This may be due to, firstly, the inevitable systematic measurement errors, especially significant for measurements at high levels. These errors can be comparable with the deformation values and in most cases taken for channel erosion and, secondly, to the redeposition of bottom material of the river within a monitoring site. Figure 2 provides the constantly changing vertical position with the greatest depth, moving from coast to coast. It is not reasonable to use fixed verticals for calculating deformations in such conditions.

The evaluation of deformations by the average depth of the channel allows us to address the inconsistencies, especially in the lateral displacement of the material. It can be obtained either from measured water discharge data, or, if there are only measurements over the cross-sectional area of the river. This technique is effective with relatively correct parabolic shape of the channel. If there are wide shore banks or other irregularities that significantly distort the connection between the average depth and the level, the calculation should be performed only for the non-dried part of the bed. Figure 3 shows that the calculation according to the average depth improves the result and, in most cases, makes it possible to relate the high-frequency component to the river's water content cycles.

It is possible to remove the high-frequency component of the fluctuations of channel bottom marks and generalize ideas about the deformation directivity by analyzing the hydraulic characteristics of the flow. One of the indicators of the dynamics of vertical deformations is the time change in the river discharge \( Q \) dependence on the water level \( H \) at this discharge \( Q = f(H) \). For approximation of dependencies we used the proposed by V.G. Glushkov [6] hydraulic and graph-analytical interpretation of discharge curves as a power function:

\[ Q = a \cdot H^m \]  

(2)
Figure 1. Time change in the river bottom marks (the Olkha river near the Olkha village), derived from depth measurements taken on the vertical in the center of the channel.

Figure 2. Time change in the position of the vertical with the greatest depth (the Olkha river near the Olkha village).
Figure 3. Time change in the river bottom marks (the Olkha river near the Olkha village), calculated by the mean depth of the channel.

Changes in the position of discharge curves integrate the dynamics of individual hydraulic-morphometric characteristics of the river, determined by the characteristics of the channel process [7, 8]. The curves $Q = f(H)$ are grouped into a narrow beam for specific periods with relative dynamic equilibrium. The downward movement of the curves indicates the channel entrenchment, since at the same discharge the water level can sink. Conversely, the upward movement of the curves indicates an increase in the river bottom. The above reasoning is valid only if there is a slight variability in the channel capacity, i.e. relative stability of the lower reaches of a river [9, 10].

Water levels during the passage of some fixed discharge for all curves give an idea of changes in the channel height. Various options are offered as fixed discharges by different authors. For example, the average of the maximum annual discharges, the half of the average maximum [3], the maximum before the water reaches the floodplain, and the annually recurring minimum discharge, which is slightly higher or equal to the average low water discharge [4], etc. It seems that each of these proposals is more or less arbitrary.

In fact, the level value obtained from the curves does not reflect the actual position of the bottom, but only makes it possible to compare these levels with each other to obtain an idea of the deformation directivity. Figure 4 shows the calculation results of these levels at the discharge of different probability. It is evident that the graphs are exactly the same and differ only in height. At the same time, none of the graphs can be considered the real position of the bottom.

Figure 5 shows the level changes $\Delta H$ between years: $\Delta H = H_i - H_{i-1}$, where $i$ is the ordinal number of the year. The value, in fact, is the relative magnitude of deformation. As can be seen, the values $\Delta H$ are the same for different discharges. Therefore, there is no point in choosing any special discharge, trying to justify this choice. It is easier to agree to use a discharge value, the calculation of which is the least time consuming, for example, the discharge rate with probability of 50%.
Figure 4. Time change in the river bottom marks (the Olkha river near the Olkha village), calculated according to curves $Q = f(H)$ at discharges of various probability (figures at lines).

Figure 5. Changes in channel marks of the Olkha river near the Olkha village between years, calculated according to curves $Q = f(H)$ with discharges of various probability: 1 – 10%, 2 – 20%, 3 – 50%, 4 – 80%, and 5 – 90%.
4. Conclusions
The proposed scheme for calculating the vertical deformations by the mean depth of the channel provides tools for determination their absolute values and to study in detail the processes of material transfer in separate phases of water content. The only limitation here is the low quality of initial information.

Calculation of discharge curves can serve as an effective means of regional research, zoning and river typification not giving absolute values of vertical deformations. Changes in channel capacity in the lower sections limit the use of this technique.

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