The assessment of Ukrainian riverbed deformation

ALEXANDR G. OBODOVSKY
Geographical Faculty, Kyiv National Taras Shevchenko University, Vladimirska St., 64 Kyiv-33, 01033, Ukraine
obodovskiy@mail.univ.kiev.ua

Abstract Two types of riverbed deformation (vertical and horizontal) were assessed for Ukrainian rivers. In zones of mixed forests and forest-steppe, vertical deformation was manifested in the form of a decrease in water levels, with associated washing out of the riverbed. For rivers of steppe zone and some rivers of forest-steppe, vertical deformation was manifested in the accumulation of alluvium due to increasing water level. Freely meandering rivers are characterized by intensive horizontal deformation in the zone of mixed forests. The least horizontal deformation is observed for in-cut riverbeds. Criteria are provided which allow for the assessment of both vertical and horizontal deformation types.

Key words activity of rivers; criteria correction; riverbed deformation types; riverbed formation; Ukrainian rivers

INTRODUCTION

Riverbed deformation reflects space and time dynamics of riverbed processes. It is one of the components in the structure of hydroecological analysis (Obodovsky, 2001). River deformation varies in direction (vertical and horizontal) and rate as influenced by various human and natural factors.

Riverbed deformation develops freely, if soil resistance towards washing out is not significant. It was observed that rivers with soil beds and banks are easily erodable. In the Ukraine, such rivers are located in the territory of Polessie, Pridneprovska (Dnipro) and Prichernomorska (Black Sea) lowlands. Development of riverbed deformation is limited if the resistance ability of covering soils is more than the washing ability of the flow. Such regions are located in the territory of Ukrainian crystal shell, at Podolskaya and Priazovskaya (Azov Sea) uplands. Depending on riverbed course development, there are two types of riverbed deformation (Chalov, 1981, 1994):

(a) vertical–attenuation or denudation, which cause transformation of longitudinal river profile and changes of level of river bottom;
(b) horizontal–migration of channel.

Scientists have defined one more type of riverbed deformation: movement of alluvium masses, resulting in spit, rifts and sandbanks (Makaveev & Chalov, 1986).

This work presents a discussion on the first two types of river deformation in the lowland part of the Ukraine.

DATA

In order to define the intensity and direction of vertical deformation for Ukrainian rivers, the author chose 52 hydrological stations (later HS), located at 37 lowland rivers. Curves of the relationship between water discharge and water level were drawn for the hydrological stations for the period 1960–1997. On average, 6–7 curves per station covering 5 to 6 years each were produced. The total number of curves produced was approximately 350.

Besides the above data, in order to find criteria for riverbed deformation assessment, the author has applied the data for the period 1963–1997 to changes in water levels (ΔH) and changes in grade of alluvium ($\Delta\ d_{50}/d_{95}$) (d_{50}, value of average fraction, mm; d_{95}, value of maximum fraction, mm) for those rivers.

Horizontal riverbed deformation was assessed using the data from 53 parts of riverbeds, located at 39 lowland rivers of the Ukraine. Spatial changes of the riverbeds location were defined by comparison of large-scale maps produced between 1923 and 1992. The earliest map was for the Sluch River, Sarny town.

In order to assess more objectively horizontal riverbed transformation, the author used relative indicators of: B/z_{cp} (B, width of riverbed in low water period, m; $z_{m.}$ is average intensity of bank washing out during many years, m) and $Q_{фр}/Q_{ЭДВ}$ ($Q_{фр}$ is riverbed forming discharge, observed within the limits of river course lines, m^3 s^{-1}, $Q_{ЭДВ}$ is minimal water discharge, which does not cause environmental damage in the period of low water, m^3 s^{-1} (Obodovsky, 2001).

All primary information on morphometry of riverbeds, bottom alluvium, water levels and discharges was taken from resources on surface waters (annual and long-term data).

METHOD

Hydrological methods were applied to investigate vertical riverbed deformation. The most reliable method is to analyse curves of relevant water levels and water discharges: $Q = f(H)$ (Makaveev & Chalov, 1986; Tsayts & Obodovsky, 1993). Up or down displacement of the curves in correlation charts correspondingly shows accumulation of alluvium or riverbed erosion. Change in water level, having the same discharge, shows intensity of accumulation or deep erosion at a river section. During the investigation the flood plain component of the curves was eliminated to allow for a more objective assessment of riverbed vertical deformation.

The method above only provides general direction of vertical riverbed deformation. The depth of flow significantly distorts the curves. Therefore, the dimensionless indicator $\Delta H/h_{ЭДВ}$ (ΔH is a decrease or an increase in water level, m; $h_{ЭДВ}$ is average depth of flow in case of minimal water discharge, which does not cause environmental damage, m) was suggested. Use of this criterion allowed for the effective evaluation of water level dynamics with river depth during low water periods. Change in grade of river alluvium can be tracked using $\Delta\ d_{50}/d_{95}$. This formula characterizes changes in relatively large bottom sediments over time. The two criteria can be related as follows:

$$\Delta H/h_{ЭДВ} = f(\Delta\ d_{50}/d_{95}) \qquad (1)$$

Using these criteria in conjuction with regression analysis allows for the assessment of the influence of the above parameters on the unlimited and limited manifestation of riverbed deformation. Hydromorphological analysis (combining of topographical maps of the same scale [1:50 000, 1:25 000], made in different years) was applied during horizontal riverbed deformation investigations. Average annual intensity of deformation (z_{cp}, m year^{-1}) at a given riverbed cross-section is expressed as:

$$z_{cp} = z/N \quad (2)$$

where z is the amplitude of displacement of the bank line, m; N is the number of years between maps.

An additional objective way of assessing horizontal deformation for lowland rivers, is by relating the following ratios; riverbed width (at low water) (B) to average annual intensity of planned deformation (z_{cp}) to relative course-forming discharge ($Q_{\text{фр}}$) and minimal water discharge, which does not cause environmental damage ($Q_{\text{ЭДВ}}$) (Obodovsky, 2001):

$$B/z_{cp} = f(Q_{\text{фр}}/Q_{\text{ЭДВ}}) \quad (3)$$

In addition to the above river deformation analysis, river width (B/h [B is riverbed width in low water period, m; h is depth of riverbed in low water period, m]) was assessed to characterize widening of the riverbed (Velikanov, 1958). The value of relative width of river is not the same in conditions of unlimited and limited development of riverbed processes. In conditions of unlimited development, it increases during active manifestation of horizontal riverbed deformation; in the conditions of limited development and of permanent erosion of riverbed, it decreases. Criteria, relating widening of riverbeds with flow related riverbed formational activity, are:

$$B/h = f(Q_{\text{фр}}/Q_{\text{ЭДВ}}) \quad (4)$$

$$B/h = f(P_{Q\text{фр}}) \quad (5)$$

where $P_{Q\text{фр.}}$ is probability of riverbed forming discharge, observed within the limits of river course lines, %.

Criterion (Equation 4) enables the analysis of the impact of relative flow related riverbed formational functions on the widening of riverbeds. Criterion (Equation 5) assesses the impact of riverbed forming discharge on the riverbed itself (Obodovsky, 2001). In order to assess these criteria, regression and correlation analyses were used.

RESULTS AND DISCUSSION

Concerning vertical riverbed deformation, analysis of space and time dynamics of criterion $Q = f(H)$ for lowland rivers of Ukraine showed quite clear regularities. The majority of rivers located both in mixed forests (Polessie) and forest-steppe are characterized by a general decrease in water levels for relevant discharges and "subsidence" of riverbeds. For freely meandering rivers, its value differs from 0.20 cm year^{-1} (the Styr River, HS Zhyrovtsy) to 3.05 cm year^{-1} (the Desna River, HS Letki). For riverbeds flowing in conditions of limited development of riverbed deformation, this value is much lower and it is from 0.0 (the Ros River, HS Korsun-Shevchenkovsky) to 1.05 cm year^{-1} (the Southern Bug River, HS Sabarov). This shows vertical deformation associated with erosion processes in riverbeds.

Tendency for water levels to increase was observed for the majority of rivers in the steppe zone (in particular, tributaries of the Seversky Donets River and rivers near the Azov Sea) and for some rivers in the forest-steppe zone (the Psel and the Vorskla Rivers). This is explained by deposition of alluvium in the riverbeds and domination of deposition processes. The biggest increase in water levels was typical for the rivers in conditions of unlimited development of riverbed deformation and it fluctuates from 0.04 cm year^{-1} (the Seversky Donest River, HS Chuguev), to 1.45 cm year^{-1} (the Obitochnaya River, HS Primorsk). For in-cut riverbeds, average values change from 0.02 cm $year^{-1}$ (the Seret River, HS Chortkiv) to 1.29 cm $year^{-1}$ (the Kalchik River, HS Kremenevka).

Criteria assessment of vertical riverbed deformation enabled us to define the following relationship (approximated by level of regression for the rivers in conditions of unlimited riverbed formation):

$$\Delta H/h_{ЭДВ} = -1.89\ (\Delta\ d_{50}/d_{95}) - 0.04 \qquad (6)$$

Error here is $\sigma = 0.92$, correlation coefficient is $r = -0.67$ (Fig. 1(a)).

Equation (6) shows that when the criterion $\Delta\ d_{50}/d_{95}$ increases (namely, when alluvium grade decreases), subsidence of water levels in riverbeds increases. It shows how active processes of erosion influence alluvium in the riverbeds (the Styr, the Goryn, the Uzh, the Desna, the Sula rivers), and how a decrease in $\Delta\ d_{50}/d_{95}$ and an increase in $\Delta H/h_{ЭДВ}$ shows

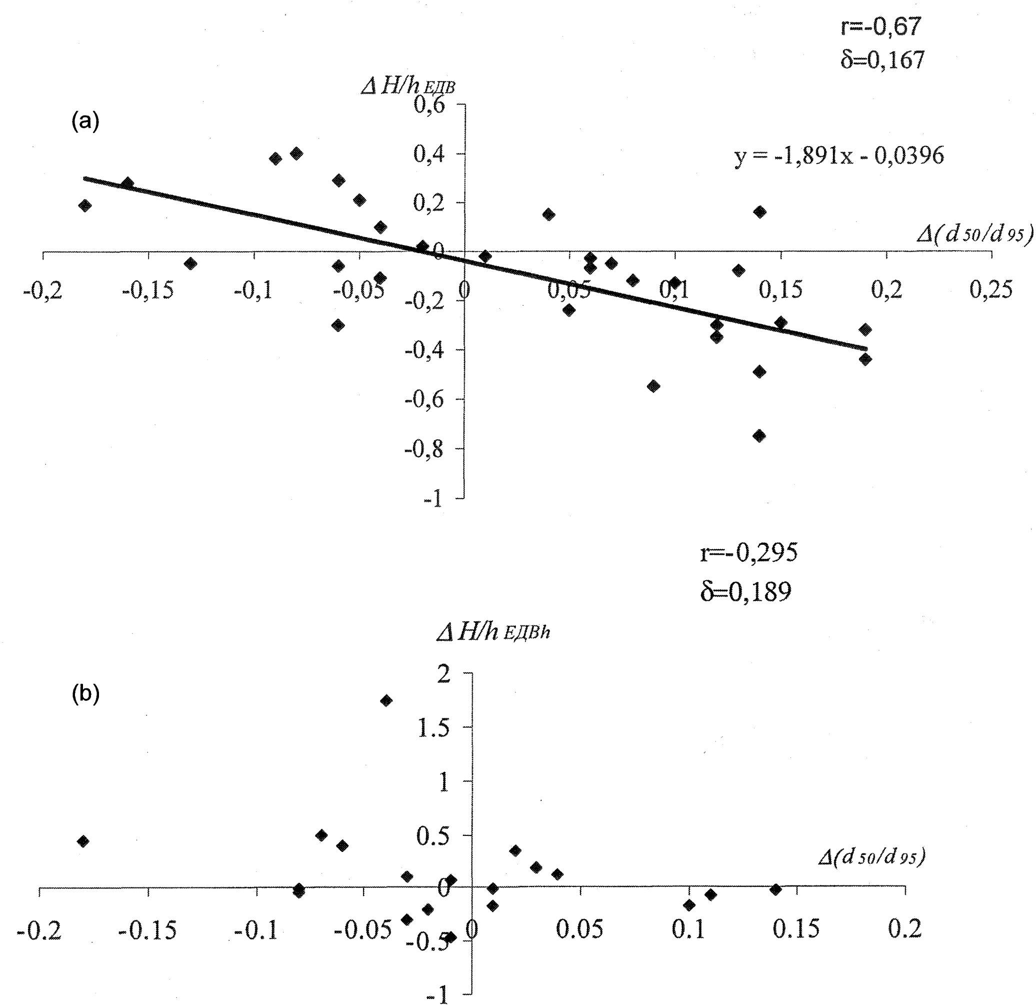

Fig. 1 Charts of Dependencies $\Delta H/h_{ЭДВ} = f\ (\Delta d_{50}/d_{95})$. (a) for rivers of Ukraine, flowing in conditions of free development of riverbed deformations; (b) for rivers of Ukraine, flowing in conditions of limited development of riverbed deformations.

increasing heterogeneity of riverbed alluvium with concomitant "accumulative" direction of vertical deformation (Opel, Samara, Seversky Donets, Molochnaya, Obitochnaya rivers).

For rivers flowing in conditions of limited development of riverbed deformation, there is no correlation between the above parameters ($r = -0.29$) (Fig. 1(b)). Therefore, processes of riverbed formation were mainly dependent on geological and geomorphologic structure of the riverbed with flow playing a less active role.

The highest intensity of horizontal riverbed deformation is typical for rivers in conditions of unlimited riverbed formation. On average, its value varies from 0.20 m year^{-1} (the Vorskla River, HS Chernetchina) to 5.65 m year^{-1} (the Sluch River, HS Sarny). These indicators are significantly smaller and fluctuate from 0 for the riverbeds where limited conditions of riverbed formation dominate (the Southern Bug River, HS Alexandrovka) to 1.97 m year^{-1} (the Ingulets River, HS Mogilevka).

Criteria assessment of this type of deformation showed that conditions of their unlimited development can be expressed by the following regression formula:

$$B/z_{cp} = 3.32(Q_{фр}/Q_{ЭДВ}) + 16.76 \quad (7)$$

with error $\sigma = 6.72$ and correlation coefficient $r = 0.71$ (Fig. 2(a)).

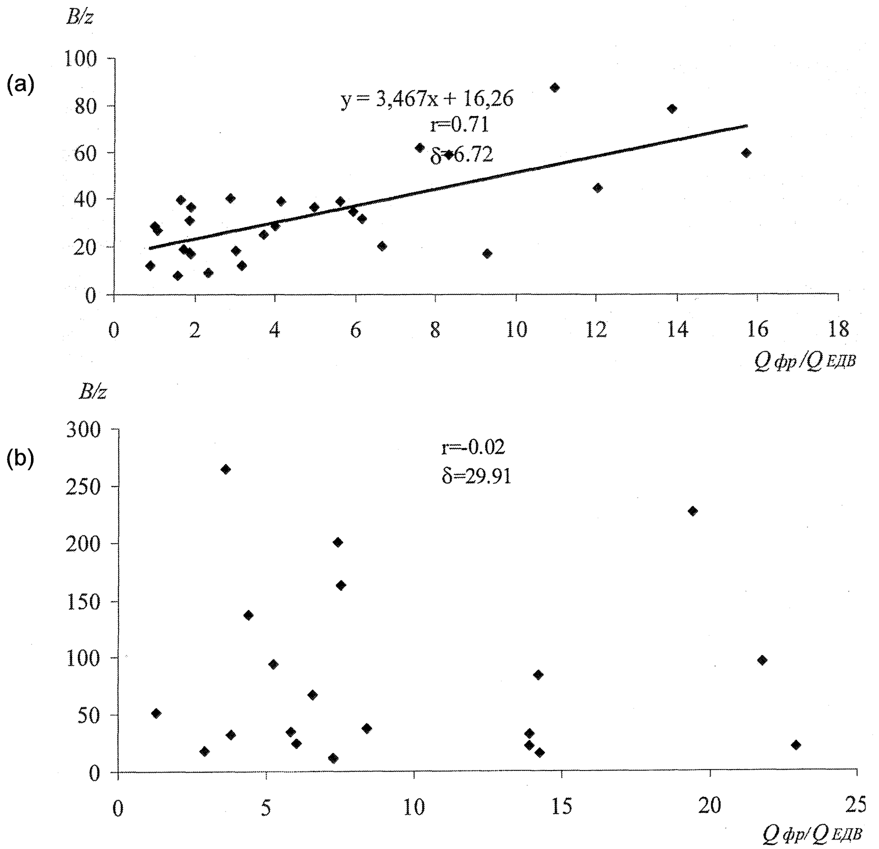

Fig. 2 Charts of dependencies $B/zcp = f(Qфр/QЭДВ)$ (a) for rivers of Ukraine, flowing in conditions of free development of riverbed deformations; (b) for rivers of Ukraine, flowing in conditions of limited development of riverbed deformations.

Equation (7) shows that an increase in relative riverbed forming water discharge leads to an increase in relative widths of the riverbeds and a decrease in the scale of horizontal deformation compared with riverbed morphometry. There is no such correlation ($r = 0.02$) for the rivers located in conditions of limited manifestation of riverbed deformation (Fig. 2(b)). Here flow and bank erosion depend on geology.

Analysis of changes of relative riverbed width (spreading), caused by riverbed formation activity of flow, shows different correlations for rivers in conditions of unlimited and limited riverbed formation. In the first case, there is a clear tendency for relative width of riverbed to increase, if relative riverbed forming discharge increased. This is shown in the following equation;

$$B/h = 2.35\ (Q_{фр}/Q_{ЭДВ}) + 23.61 \qquad (8)$$

with error $\sigma = 8.7$ and direct correlation $r = 0.68$ (Fig. 3(a)).

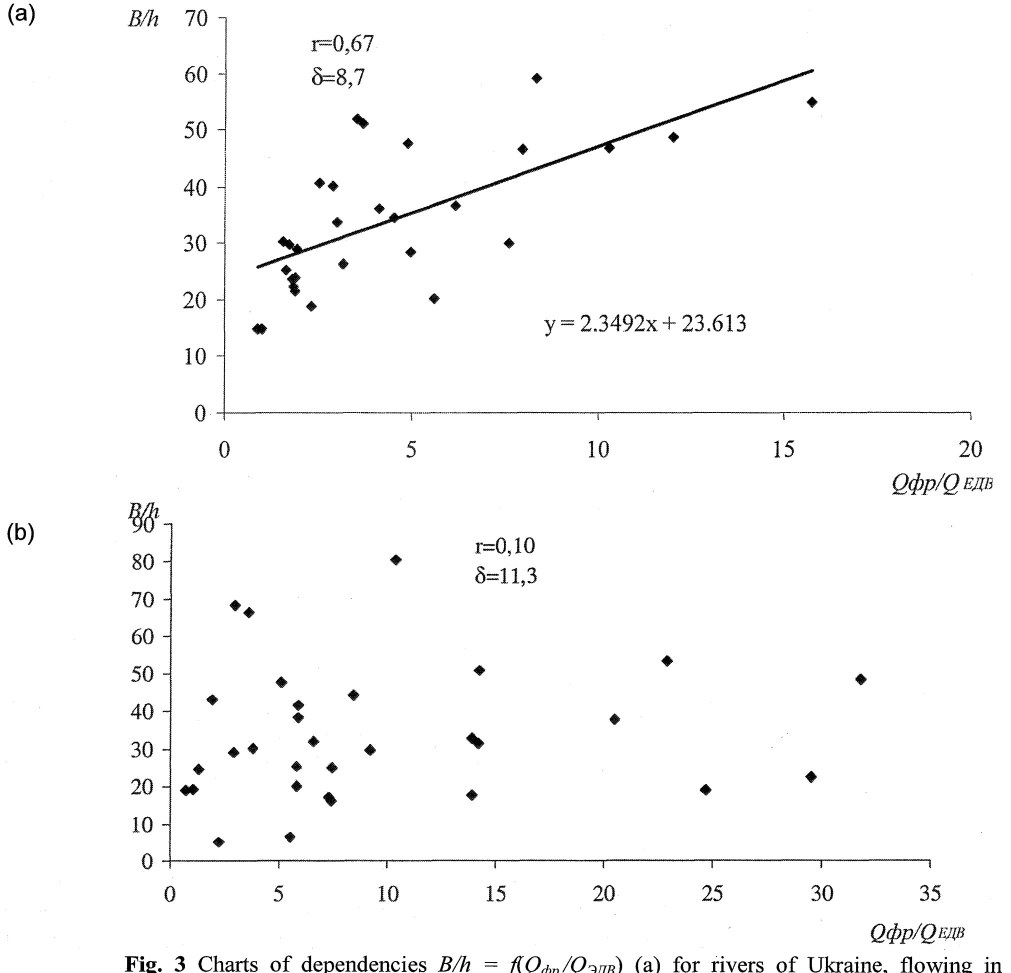

Fig. 3 Charts of dependencies $B/h = f(Q_{фр.}/Q_{ЭДВ})$ (a) for rivers of Ukraine, flowing in conditions of free development of riverbed deformations; b) for rivers of Ukraine, flowing in conditions of limited development of riverbed deformations.

At the same time, in conditions of unlimited riverbed formation, when water supply $Q_{фр}$ (namely, absolute values of discharges) increases, relative width of the riverbed also increases. This is expressed by the following equation:

$$B/h = -0.47(P_{Qфр}) + 44.71 \quad (9)$$

with error $\sigma = 22.1$ and reverse correlation $r = -0.57$ (Fig. 4(a)).

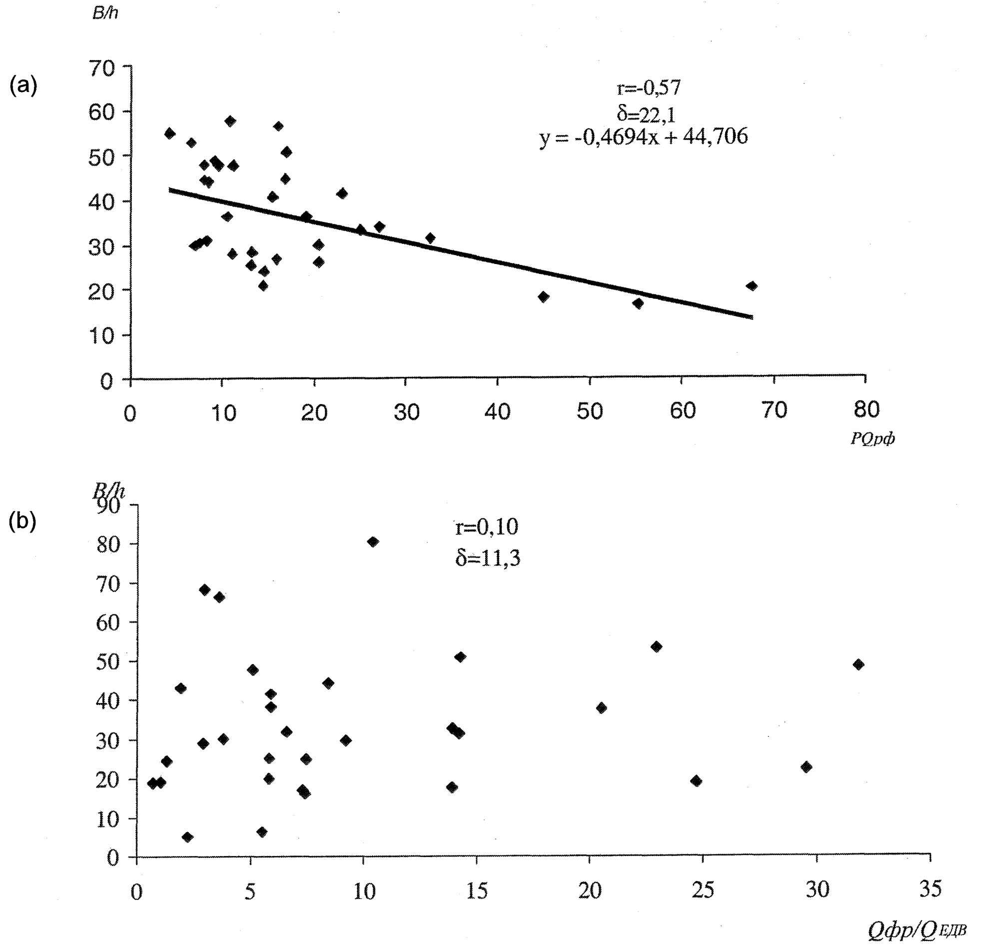

Fig. 4 Charts of dependencies $B/h = f(PQфр.)$ (a) for rivers of Ukraine, flowing in conditions of free development of riverbed deformations; (b) for rivers of Ukraine, flowing in conditions of limited development of riverbed deformations.

The above demonstrates that the greater the discharge, the greater is the potential for meandering (deformation) of the riverbed. For rivers in conditions of limited development of horizontal riverbed deformation, there is no correlation, described by the above equations (Figs 3(b), 4(b)). They show that neither lower relative riverbed forming discharges, nor their absolute values in the given conditions affect the establishment of riverbed morphometry.

CONCLUSION

Quantitative parameters of flow are the main active factor of vertical as well as horizontal manifestations of deformations for freely meandering rivers. Riverbed morphometry is to a large extent defined by space–time dynamics of grade of alluvium. At the same time, there are no such regularities for the rivers in conditions of limited manifestation of riverbed deformation. Geological and geomorphological conditions in the river basins are the main factor for riverbed formation processes.

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