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RIVERBED FORMATION REGULARITIES IN PEREDKARPATTIA RIVERS (WITHIN THE TERRITORY OF UKRAINE)

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Abstract:

This article is devoted researches of regional and general regularities in the riverbed formation in rivers with huge movable beds in places where stream outcomes onto widened valley bottom areas. We well know that, disclosure of regularities in riverbed structure and riverbed processes development is important both theoretically and practically. It is particularly essential when it comes to the Peredkarpattia which still is an understudied region. The lack of knowledge is evident from the events that took place at the end of the previous and in the first decade of the present centuries – an extremely high floods that caused human losses and massive destruction of agricultural lands, constructions and communications.

Keywords: *geo-hydro-morphological analysis, “stream-riverbed” system, flood regime, fluvial sediments, alluvial plains, huge movable beds, homogeneous plots, riverbed formation regularities.*

INTRODUCTION. The study of the regularities in riverbed formation in rivers of mountainous regions is important in both theoretical and practical aspects. It is particularly important when we speak of areas where rivers run into the limits of valley bottom expansions (alluvial plains) which represent the settled and intensely used territories. Therefore, we shall accentuate upon foothill (submountain) rivers that are also distinctive for their complex flood regime. To help deepen the knowledge on riverbed formation regularities, these rivers (and huge movable beds on the whole) require their thorough study on the basis of present-day doctrines and approaches of riverbed knowledge as well as on the basis of geo-hydro-morphological approach and with the use of new methods and ways of scientific research. In particular, it is important to study not only the specific examples of riverbed formation on the river single plot, but its whole variety studying the river along its course.

The environment composed of beaching from fluvial sediments is specifically characteristic for inclined alluvial plains where pre-arranged deformations are more compound and dynamic, thus adding to the complexity of study of regularities in riverbed development and to ability of river use. It is important to take into account both age changes in riverbed and high-water bed morphology, and specific riverbed deformations, especially those involved into activity of greatest floods.

The Peredkarpattia may serve as a methodical testing area for riverbed studies due to both specific and typical character of riverbed formation and its practical significance; due to anthropogenic changes introduced in such formation, as well as in connection with sparsification of hydrologic observation net and importance of gradual accumulation of expedition and other materials.

Humankind developed and deepened its practical knowledge of riverbeds and high-water beds throughout its whole history. However, it was only at the turn of the XIX and XX centuries that first theoretical knowledge was generalized. Riverbed studies enter into their active phase since mid-XX century, though some plots of the Peredkarpattia riverbeds were explored as far as at the end of the XIX century. The rivers of the Ukrainian Carpathians were put under detailed analysis in the middle of the XX century. First studies were of applied character connected with rivers' reclamation and use.

The present-day stage of the Carpathian Region riverbed knowledge begins from the second half of the 1990 and is characterized with development of the ideas as to the rational and optimal riverbed and high-water bed use and application of new methodological approaches towards the same.

Based on methodical substantiation and informational provision, this work aims at disclosure of regional and general regularities of riverbed formation in rivers with huge movable beds after their mountain course runs into expanded plots of valley bottoms (on the example of the Peredkarpattia rivers within the territory of Ukraine).

Riverbeds and high-water beds of the Peredkarpattia rivers running within the territory of Ukraine together with anthropogenic objects (inclusive of the major elements of their inner structure) at the level of characteristic and homogeneous plots represent the object of this study, while the regularities of riverbed formation in rivers of the Peredkarpattia in referent and anthropogenic conditions are the work's subject-matter.

MATERIALS AND METHODS. Reference sources, published information, analysis/synthesis and systems approach were the methods of research at the stage of problem statement. Geo-hydro-morphological approach and analysis were taken as a basis for methodology. In fact, it was a review of the riverbed cartographic and expedition knowledge methods and approaches. The stage of empiric material collection and processing was characterized by the use of the methods of computer processing of cartographic materials, satellite images and riverbed cartography [1]. Maps and satellite images (for the last 20 years) reduced to a single scale were helpful in the analysis of basic temporal changes in riverbeds state. Properly prepared and carried out, riverbed research expeditions brought the descriptions of riverbed plots and included leveling of cross/axial sections, GPS-shooting, photography (in particular, alluviation, method of photogrammetry), fixation of high water marks (after the 2008 flood). Expedition data were finally put to computer processing (cross-sections, photogrammetry, etc). The analysis of riverbed information obtained from the river division into homogeneous plots has also represented the riverbed knowledge method. The stage of generalization and search for regularities in riverbed formation was distinctive for the use of the methods of geo-hydro-morphological analysis (in particular, coordination of empiric and general (theoretic) dependences), comparative method; analysis of the links between hydrologic, morphological and hydraulic characteristics within the "stream-riverbed" system (SRS); analysis of the factors and spatial sequences in riverbed formation; geo-hydro-morphological classification. Present-day geo-ecological approaches were applied in the analysis of riverbed use problems.

RESULTS AND DISCUSSION. Disclosure of regularities in riverbed formation in the Peredkarpattia rivers (within the territory of Ukraine) requires the analysis and generalization of the effect of its major factors and most important features of riverbed morphology.

The Peredkarpattia (within the territory of Ukraine) and adjacent parts of the Ukrainian Carpathians and the Podillia which are in the first place connected with the expanded plots of river valley bottoms filled with alluvium (alluvial plains) were chosen to be the territory of our studies. The territory is conventionally called a hydrologic-riverbed-knowledge Peredkarpattia since it comes out of the limits of the geomorphologic Peredkarpattia.

The "stream-riverbed" system and the processes of riverbed formation are operated by the extremely complex set of factors. To discern the regularities in riverbed formation in rivers running from the mountains and developing within the foothill limits, we had to trace peculiarities of major factors and their changes down the stream. As a result, we developed a functional-basin scheme of the analysis of factor effects that includes the same of the transitional factors formed in the upper area of the river basin, and of the local factors (see Figure 1).

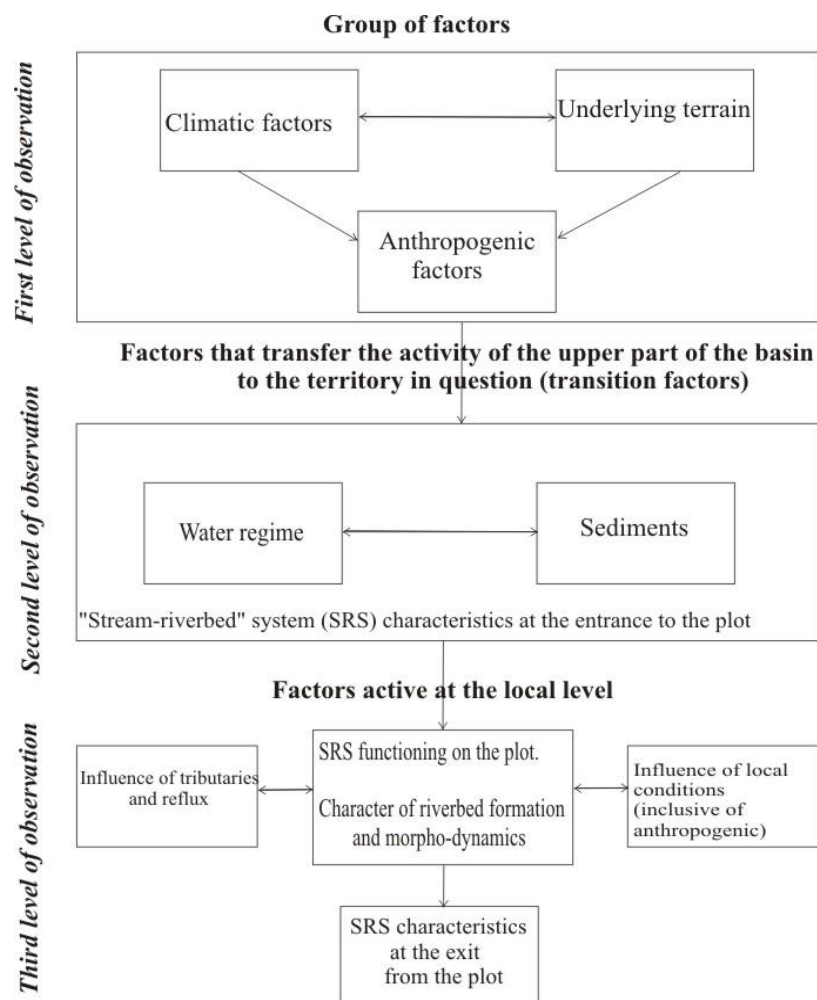


Figure 1. Functional-basin scheme of riverbed formation factors.

Water regime is an important riverbed formation factor characterized by frequent floods within the limits of the studied territory. Water expenditures are scarcely measured in the period of floods. It is also worth noting that the territory of the Peredkarpattia is poorly covered with hydrologic observations which was among the reasons to make use of the expedition data. To analyze water expenditures during the floods we had to choose an appropriate method and suggested the one of expenditure correlation through the modules of flood runoff. This allowed for the analysis of water maximal expenditures and the assessment of hydraulic and other characteristics. The method helped to reveal stage gauges (observation points) that were giving in published materials the understated data on maximal water expenditures before 2008, but the data on 2008 flood fundamentally changed the situation.

The data of hydrological observations and our own expedition materials were the basis to help study the sediment (as one of the major factors for riverbed formation) granulometric composition. We built the integral curves of granulometric composition for hanged and bottom sediments, using, in particular, the photogrammetric method. After the data were processed and the integral curves of the distribution of sediment granulometric composition were analyzed, we came to the conclusions as follows: where hydrological observations are concerned, the samples containing the maximum of sediments should be considered as riverbed-forming; as we go forward from the mountains, the

gradation and unidirectionality in sediment composition changes is observed; different portions of cross-section show significant difference in sediment composition.

Alluvial environment for riverbed formation starts its development as far as in the mountainous areas within the limits of valley bottom expansions. After the rivers run out into the foothill with considerable transportation of huge load and decrease of side limitations, the riverbeds bifurcate and gradually form inclined alluvial plains. Their geo-morphological and riverbed-knowledge description is based on peculiarities of present-day terraces and includes the description of the thickness of different facies of the alluvium, etc. This represents the specificity of the factor of limitation influencing the “stream-riverbed” system and we therefore pay it our particular attention. Peculiarities of riverbed formation conditions within alluvial plains can be considered on different hierarchical levels and we suggest four such levels of consideration, each of them having its own scheme (plan). An overview map that shows alluvial plains against the background of the territory’s general and major orthotectonic structures was suggested on the first (the highest) level. The same of the alluvial plains of the second order based on the 1:100 000 topographic maps were considered on the second level. Overview/analytical maps of the alluvial plains of the second order were composed on the third level. The maps show expanded plots of valley bottoms of specific (major) rivers within the alluvial plains of the first order, connected with specificity of the territory’s tectonic structure (as a rule, more homogeneous genetically and with own specificity). The maps also demonstrate major specificities of the valley bottoms’ inner relief; generalized limits of longstanding strips of riverbed and high-water beds formation, and the limits of homogeneous plots. And finally, we outlined analytical maps of the portions of alluvial plains of the second order on the fourth level of consideration. The maps indicate the river valley bottom relief details (and the hydrographic net as a bottom structure indicator) and availability of bedrock exposures to help analyze local conditions that develop “stream-riverbed” system.

The last decades were remarkable for the decrease of plots with referent conditions in rivers within the studied territory and the increase of anthropogenic load in the river basins due to active economic activity and riverbed and high-water bed transformations. This is why it seems important that the studies of the Peredkarpattia rivers’ riverbed formation regularities considered the anthropogenic load as a separate factor.

We have also developed the concepts of the riverbed morphology and morphodynamics as well as of their temporal-spatial changes in the Peredkarpattia rivers: homogeneous plots of the riverbeds and high-water beds in the region were outlined and described; riverbed local forms were characterized; specific types of riverbed deformations were described and analyzed. The totality of 100 homogeneous riverbed plots and high-water beds in 18 major rivers within the studied territory were outlined and their sequences along the rivers within the alluvial plains described. It was only partially that the rivers of lower orders and chutes were explored, since such exploration reveals (if compared) the difference in the influence of riverbed formation factors. In the temporal aspect and for purpose of factor impact analysis, we outlined referent and anthropogenic conditions of riverbed formation, and riverbed and high-water bed development. We started with the study of cartographic materials, satellite images and air photos, descriptive and other materials with regard to conditions that were not significantly changed by human activity, these followed by detailed expedition research. Anthropogenic changes in riverbeds and high-water beds were the next stage of the study. Dividing rivers into plots and making their riverbed-knowledge description, we majorly paid attention to the effect of side limitations, compressions, riverbed and high-water bed structure peculiarities, changes in riverbed formation width, etc.

The study of riverbed mega-forms and their prevailing or dominant forms covers the period of nearly 120 years. Having analyzed the source information, we disclosed and described basic types of riverbed mega-forms and specified temporal changes in the riverbed basic forms. Closer to mountains, there prevail extended forks with big islands or their complexes. Broad local forks (islands, island systems) are characteristic for the plots of alluvial plain expansions. Mega-meanders (inherited or gradually

formed) were disclosed within the plots where riverbeds of the minor rivers are incised and inserted. Classical mega-meanders (complex high-water bed massifs) are also encountered in the rivers within the studied territory. The Chechva and Sukil Rivers are distinctive for the estuary protrusions, while bigger rivers such as Bystrytsa-Dniester, Cheremosh-Prut demonstrate the formation of complex junction nodes.

The Peredkarpattia rivers are less characteristic for riverbeds developed as chains with homogeneous dominant forms than those in the plain, this effected by the following major factors: complex tectonic structure (effects of limitation factor and local conditions), a big lot of transported riverbed-forming load, and a complex high-water regime. The riverbed structure, at the same time, allows for outlining of more typically occurring forms that prevail on riverbed and high-water bed homogeneous plots and represent the elements of complex or simple riverbeds. Meandering is observed within the limits of bifurcated riverbeds with long chutes, while complex branched riverbeds hardly demonstrate macro- and meso-forms which are more vividly expressed in high-water bed bifurcation and less expressed in riverbed multi-channels. It is worth noting that we did not manage to find out side heads in bifurcated riverbeds. Instead, cells or meanders of different stage of development occurred. Majorly meandering riverbeds show a more expressed regularity of dominant forms than those that are branched. Depending upon local conditions, meanders are of different forms. We met adapted and inserted meanders, and their longstanding dynamics can be in some cases disclosed.

Specific cases (types) of dominant form deformations were analyzed in detail to help deepen the concepts of riverbed morpho-dynamics in rivers of the Peredkarpattia. We took into account that characteristic (regular) changes in riverbed formation occur on the transition from the stream upper portion to its lower portion, from mountain conditions to plain conditions, especially with the development of the alluvial environment. Peculiarities of riverbed and high-water bed homogeneous plots were also considered. Having analyzed typical types of longstanding deformation we find it worth noting that average intensity of side (pre-arranged) shifts of riverbeds in the majority of the Peredkarpattia rivers amounts to approx 5-7 meters per year.

Since geo-hydro-morphologic approach suggested by Yu.S. Yushchenko [2] was taken as a basis for our research; we aimed at its development on the grounds of our empiric materials from the Peredkarpattia; at deepening and specification of disclosed regularities of riverbed formation in rivers with big alluvium in conditions of the distance from the mountains; and at finding out and analyzing new such regularities.

Using functional-basin scheme and structural-classification (geo-hydro-morphologic) table for the purpose of consideration of riverbed formation factors, we should remember that the character of water regime and floods are formed as far as in the mountains and experience little changes in the foothill. This is why it is local conditions effecting upon the structural transport of sediments reflected in the formation of riverbeds that must be considered in the first place. This is a very important regularity. The big size of benthal sediments is a good indicator of valley bottom lengthwise inclinations and corresponding peculiarities of the “stream-riverbed” system functioning. In particular, this is evident from the diagram of the dependence of river lengthwise inclinations upon riverbed-forming water expenditures and average size of benthal sediments. The diagram is built for the conditions of the Peredkarpattia on the grounds of our empiric materials, where I_0 (river valley bottom lengthwise inclination in the strip of riverbed formation) represents the values taken as mean values for corresponding riverbed and high-water bed homogenous plots to represent; \bar{d} – average diameters of riverbed-forming sediments (estimated during the expedition), and Q_p (riverbed-forming water expenditures) stands for flood expenditures with 10-15% provision. As a result, we can speak about general (uniform) regularities in alluvial riverbed formation.

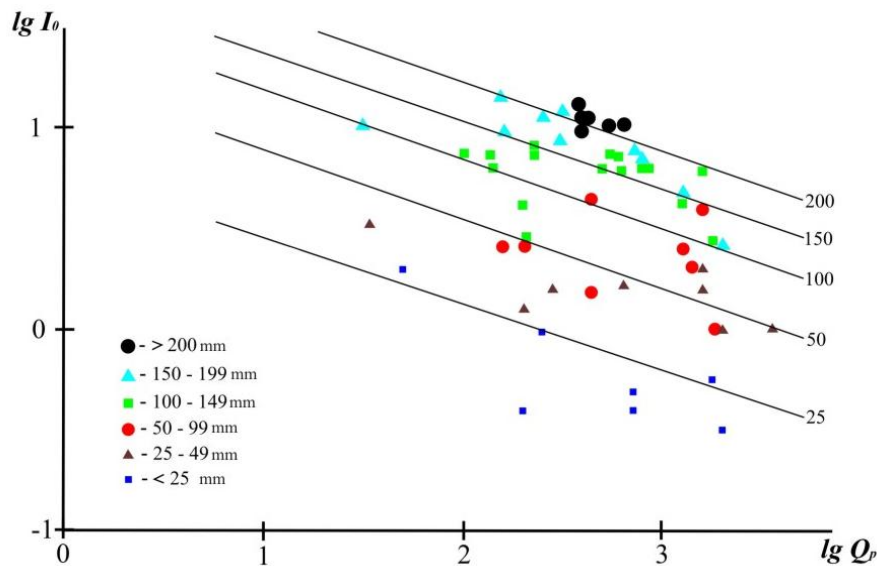


Figure.2 Dependence diagram $I_0 = f(Q_p; \bar{d})$.

Using the geo-hydro-morphological analysis, we generalized the data on riverbed morphology. In the first place, we took notice of the forms connected with concentrated and more holistic stream. In fact, they occur within the majority of riverbed and high-water bed homogeneous plots and can be regarded as basic or dominant forms. Secondary forms are those of less size. They occur more often and are the “stream-riverbed” system’s response to the needs of transport and sorting out (re-sedimentation) of a big quantity of riverbed-forming load in complex and changed local conditions. The steps data were taken from topographic maps and Earth’s remote sounding, and with consideration of the riverbeds’ old positions. Flood expenditures with 10-15% provision were taken as riverbed-forming expenditures. The $L = f(Q_p)$ dependence is shown in Figure 3.

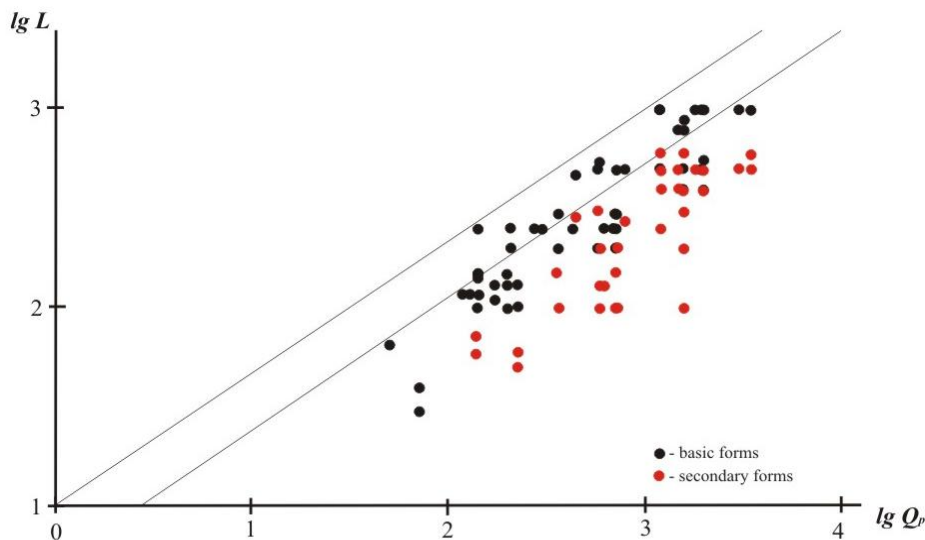


Figure.3 Dependence diagram $L = f(Q_p)$.

This example demonstrates the essential correspondence with general dependence. That is, the SRS may reach the active states of geo-current despite the complexity and diversity of local conditions. At the same time, it seems necessary to deepen the knowledge of secondary forms.

The character of the relief, lengthwise profiles, benthal sediment size and runoff changes definitely indicate to flow intensity and sediment transport decrease. All these also impact the stream energy, its energetic characteristics and peculiarities of inner processes of self-organization. Energy is expressed by the Froude numbers (kinetic indicator). We built a diagram showing dependence between the Froude numbers and mean diameter of riverbed-forming sediments (see Figure 4). It clearly demonstrates that such dependence exists and is expressed and characterized by the bend applicable to Froude number of approx 0.5. Remembering that sediments largeness is connected with the processes of their hydraulic sorting, we may come to the conclusion that the specificity of this process changes with the decrease of the level of kinetic stream to 0.5. We should at the same time note that the values of average Fr_c correspond to $Fr_{max} = 0.8$ and more which is peculiar for mountain rivers. Thus, the peculiar, extremely intense and active processes may develop during the greatest floods on the plots that show the values exceeding the Froude numbers.

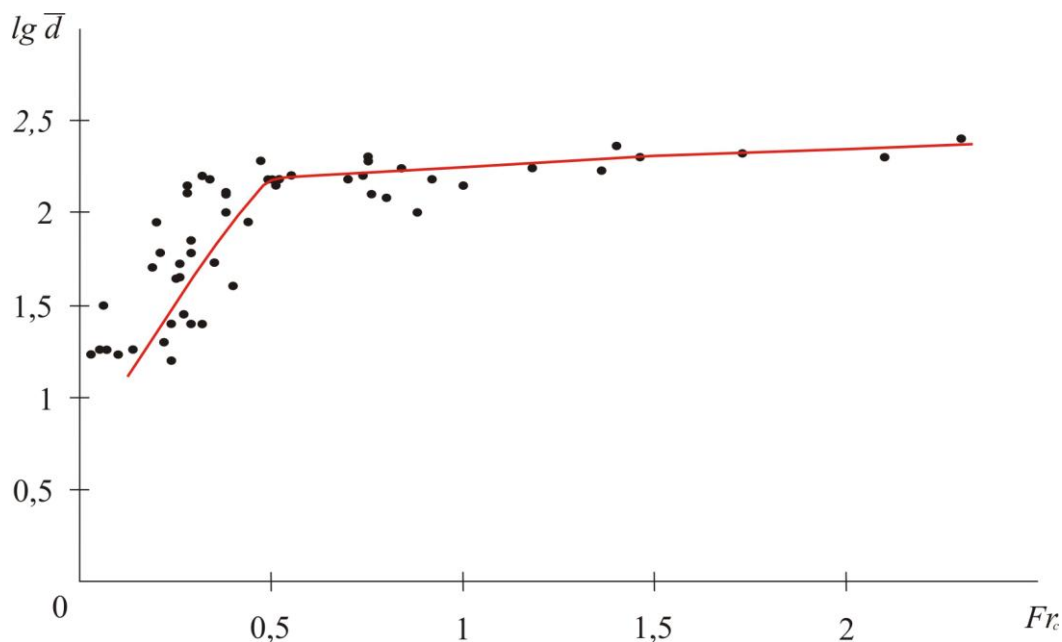


Figure.4 Diagram of links $\bar{d} = f(Fr_c)$.

Peculiarities of benthal sediment transport organization on specific homogeneous riverbed and high-water plots can be assessed by their moving ability. The diagram on Figure 5 shows the principal dependence and the region of significant deviations. That is, the principal dependence represents an objective regularity of stream kinetics decrease along the flow of the mountain and semi-mountain rivers. Alongside with that, there exist complicating processes and factors connected with local conditions (compression) and sediment transport peculiarities (effect of sediment factor). The diagram of dependence, with the same scales has an angle of 45°. Additional (side) lines limit the point positions deviating 20% from the central line (it corresponds to precision of estimation $v, \frac{v}{v_0}, Fr_c$).

The character of such dependence is changing within the range of Froude numbers from 0 to 0.5-0.55 (major zone of alluvial plains). The $\frac{v}{v_0}$ value does not exceed 1.1 – 1.2 within many plots (gauges).

These are the ones where the speed of the stream is efficiently lowered due to resistance formed by

riverbed-forming sediments and riverbed forms. The central line is not drawn, since it must verge towards $\frac{v}{v_0} = 1$. Acceptable upward deviations amount to approx 20%, too. This part of the diagram shows that 39.4% of points deviate over more than 20%. It is explained by relative compressions and stream concentration at sufficient distance from the mountains at decreased lengthwise inclinations and riverbed-forming sediment largeness and number. All these points represent the subclass of riverbeds in developed alluvial environment with moderately kinetic stream (see HMB on Figure 6) to be analyzed hereunder. It means that highly-kinetic stream vanishes in the main current and the role and the influence of the largest sediment fractions decrease. It is evident that other dependences should be sought for the range of values of this variable. It is 26.6% of points that deviate from main dependence. The gauges (plots) located in the upper areas of alluvial plains prevail here.

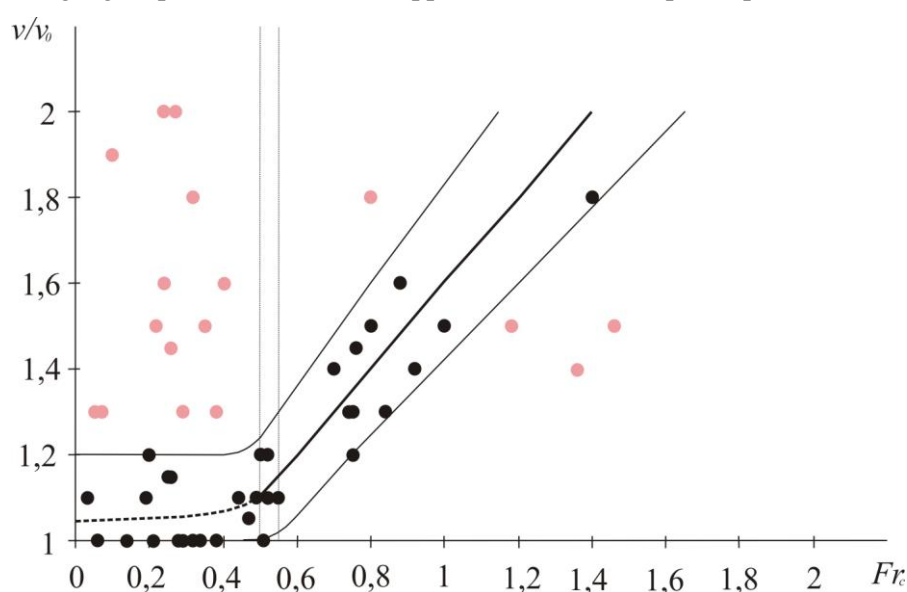


Figure.5 Diagram of links $\frac{v}{v_0} = f(Fr_c)$.

Our complex analysis of major regularities in riverbed formation allows for improvement of general scheme of such formation changes along the flow within the limits of alluvial plains, as well as for deeper understanding and explanation of certain rivers' behavior.

Our research was helpful in developing geo-hydro-morphological classification of riverbeds in rivers of the Peredkarpattia and huge movable beds (HMB) in general (see Figure 6). The scheme and the major attributes to divide HMB into classes are specified, and a new subclass, is disclosed. HMB-1: riverbeds in undeveloped alluvial environment with highly-kinetic stream; HMB-2: riverbeds in moderately developed environment with highly-kinetic stream; HMB-3: riverbeds in developed environment with highly-kinetic stream; HMB-4: riverbeds in developed environment with moderately-kinetic stream; HMB-5: riverbeds of transitional type in mixed alluvial environment with low-kinetic stream. HMB-3 and HMB-4 subclasses specify the concept of riverbed formation changes in the foothill. HMB-4 is distinctive for peculiar intro-riverbed forms and riverbed structure on the whole.

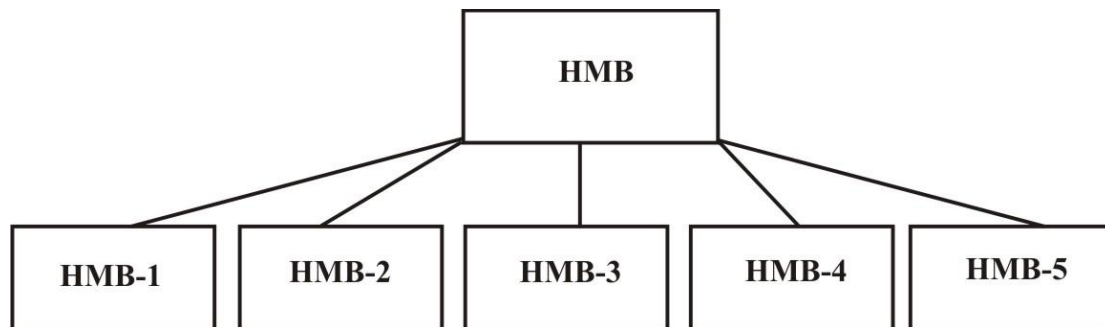




Figure.6 Scheme of huge movable beds division into subclasses.

To sum up the results of our research, the analysis of basic geo-ecological problems connected with riverbeds and high-water beds, and the causes of huge losses during the 2008 flood, we can not but outline the impact of anthropogenic factor. Our field research helped us state and analyzes main consequences of said flood. Major types of flood impact upon engineering communications were analyzed and it is emphasized that the intensity of deformations was very high. Thick boulder high-water beds, roads, bank protection constructions and even terrace banks were washed out. On the whole, the character of deformations corresponded to peculiarities of riverbed homogeneous plots and to regularities in “stream-riverbed” system functioning. Destruction of bridges took place due to lowering of pier stability caused by alluvium withdrawal in previous periods and the effects of flood, as well as due to accumulation of “wooden” sedimentation, significant decrease of throughput capacity, and local washaways. More capacious and fundamental highway stream crossings with big throughput capacity had little damage. Local washaways of roads and bank protection constructions were the other examples of riverbed deformations’ dangerous impact upon engineering communications. This is why it seems necessary that the results of our research with regard to major factors and regularities of riverbed formation in rivers of the Peredkarpattia was taken into account for the purpose of improvement of the quality of economy and life organization in both basins and on adjacent territories.

CONCLUSIONS. Disclosure of regularities in riverbed structure and riverbed processes development is important both theoretically and practically. It is particularly essential when it comes to the Peredkarpattia which still is an understudied region. The lack of knowledge is evident from the events that took place at the end of the previous and in the first decade of the present centuries – extremely high floods that caused human losses and massive destruction of agricultural lands, constructions and communications.

The present research helped us deepen the provisions of geo-hydro-morphological concept with regard to study of regularities of huge movable beds’ formation, and, in particular, rivers of the Peredkarpattia (within the territory of Ukraine). A functional-basin scheme of consideration of major factor effects is developed and realized. Links between major parameters and characteristics of the “stream-riverbed” system are disclosed. The scheme of huge movable beds’ division into subclasses is specified. Methodical questions connected with estimation of water maximal expenditures during the floods, flow speed, side limitation factor effect analysis (alluvial plains), riverbed morphology temporal change analysis, deformation assessment, etc, are solved on the basis of our own natural exploration and processing of source and reference data . The results of this study can be helpful in designing and operating of engineering constructions, in particular, those of bank protection, as well as in planning of rational use and protection of riverbeds and high-water beds in the rivers of the Peredkarpattia.

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