Hydraulic Structures that Contribute to the Sediments Directed Transfer and the Mass Transfer Activation

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Abstract. The article discusses the basic concepts of the currents ordering in the sea near-shore zone when substantial water flows come from the rivers that feed them. Some preliminary calculation schemes are considered to determine the main fundamental parameters of the systems of artificial structures that organize the flow in the seashore in order to ensure the best environmental conditions.

1. Introduction

Water resources in the area of the confluence of small rivers of the Crimea into the sea are represented by both territorial waters of the high sea and the river near-shore zone, reservoirs, ponds, quarries, springs, and other water bodies. The main environmental problems are associated with pollution from surface sources, a lack of dissolved oxygen, as well as with the deposition of a large number of suspended alluvial deposits – substances representing particles of different sizes – from several nanometers to tens of centimeters. The distribution of these particles in sediments is characterized by layering and unevenness, related to flood history and the particles sedimentation [1,2].

The re-formation of the river bottom and banks that occur during medium and large floods are of particular interest, since they determine the progress of further hydrophysical processes in this water area. In order to prevent critical, deep and planned deformations and to streamline these processes, as well as to provide their greater predictability and calculation capabilities, it is recommended to create water-forcing dams and systems of the groins without openings and the low flooded ones that restrict and regulate the flow, limit the flow and mass exchange in certain local water areas [3, 4].

When flood river flows exit into the sea water area, a large proportion of sediment is washed away. At the same time, bottom sediments are agitated with the formation of significant accumulations and re-deposition over considerable distances. It is the forecast of further transformations of silted deposits, owing to both their geometric shapes and hydraulic features, as well as to the structure of flows that attracts the most interest. The further progress of stream bed processes in this section of the river near-shore zone determines its future deformation trends. It is the correct prediction of the nature of further re-formations of the river bottom and shores that will allow us to rationally design the necessary structures and ensure the best environmental conditions for this water area [5].
The purpose of this work is to demonstrate the methodology of calculations and making fundamental design decisions when planning of the facilities that contribute to the directed transfer of sediments and the activation of mass exchange in the near-shore zone of small rivers.

2. Method development
A method of hydraulic modeling of flows saturated with sediments was developed. In general, the calculation of the similarity scaled model was performed according to Froude and according to Reynolds, that is, the Reynolds numbers for the model were more critical, and at the same time, the mode of self-similarity in viscosity was observed [6]. In the experiments with the start-up of sediments, the sediment was fed evenly in time, in an amount corresponding to the flow transporting capacity. The latter was calculated by analytical methods and tested on the model by the amount of soil removed from the model per unit of time.

To predict the velocity distribution, a so-called "flow plan" was constructed, which is a solution to a planned two-dimensional hydraulics problem using the method of M. A. Velikanov [7], used for a continuous, almost plane-parallel flow with very slight distortions in the sections of the river bed.

The method is based on the solution of the Chezy's equations [8, 9]:

\[ v = C \sqrt{R \cdot I}; \quad Q = \frac{\omega}{\chi}, \quad C = \frac{1}{n} R^{y} \]

\[ y = -0.13 + 2.5 \cdot n^{0.5} - 0.75 \cdot (n^{0.5} - 0.1) \cdot R^{0.5} \]

(1)

where \( n \) is the roughness code, \( R \) is the hydraulic radius for the entire flow under conditions of uniform movement in a prismatic river bed with a constant bottom slope \( I \),

\[ \chi = \int_{0}^{b} \sqrt{1 + \left( \frac{dh}{db} \right)^{2}} \, db \] – the wetted perimeter of the riverbed in its given section;

For each vertical within the considered section, taking into account the averaged flow rates \( v(b) \), there are elementary flow rates \( dQ \) that correspond to them

\[ v(b) = C(b) \sqrt{R(b) \cdot I}; \quad dQ = v(b) \cdot d\omega \]

\[ R(b) = \frac{d\omega(b)}{d\chi} = \frac{h(b) \cdot db}{d\chi} = \frac{h(b)}{\sqrt{1 + \left( \frac{dh}{db} \right)^{2}}}, \]

(2),

where \( b \) is the transverse coordinate of the considered vertical in the river bed and the width of the river bed along the top,

\[ \frac{dh}{db} \] – the transverse slope of the riverbed bottom on this vertical;

\( v \) – flow rate, \( Q \) – duty of water, \( C \) – Chezy's velocity factor, \( \omega \) – the cross-sectional area of the considered stream line,

The boundaries of equal-flow stream lines, according to the described technique, are determined based on the numerical solution of the following equation for each section of the river bed and when it is divided by width into N stream lines (Figure 1).
\[ Q_i = \int_{0}^{b_i} q db, \quad q_i = \frac{1}{n} R_i^{3/2} h_i \sqrt{R_i \cdot I} \]  

(3)

where \( b_i \) and \( Q_i \) - coordinates of the boundaries of equal-flow stream lines and their corresponding costs; \( i \) – the numbers of the jets, \((i=1,n)\) \( q \) – flow intensity on the vertical, \( h_i \) - vertical depth, 

\[ R_i = \frac{h_i}{\sqrt{1 + (\frac{dh_i}{db})^2}} \quad \text{– hydraulic radius on the i-th vertical.} \]

Figure 1. A diagram of a live section of a riverbed with the boundaries of equal-flow stream lines.

After obtaining boundaries of equal-flow stream lines, the velocities obtained from the hydrodynamic grid are recalculated, and on their basis, the river bed deformations are calculated according to the method [10, 11, 12]. The developed technique makes it possible to make flow plans in the space between the dams. Based on these calculations, the flow intensity of bottom and suspended sediments in each equal-flow stream line can be determined, and the deformations and the configuration of the river bed at each subsequent time can be calculated further using the equation of sediment balances.

3. Verification of the results
To test the developed technique, a hydraulic tray was used, where three-dimensional models of the Bystrica Solotvinskaya river section near the village of Yablonka were formed [13]. The experiments were aimed at tracing the hydraulic phenomena that occur while flowing round the combined groins, and the processes of forming a stable river bed in the space between the flooded groins caps, as well as at tracing the process of sediment transport during the flood peak.

Figures 2 and 3 show a schematic diagram of the construction of longitudinal dams that restrict the flow, and the creation of additional constraining structures – a system of groins consisting of the parts without openings that actually restrict the flow, and low flooded groins (semi-dams) that regulate the movement of sediments.
Figure 2. The scheme of creating a stable river bed with its optimal constraint by combined semi-dams (groins).

Figure 3. The design of a combined semi-dam (groin), consisting of a trapezoidal cross-section part without openings and a low flooded part located at an angle of 45 degrees towards the flow.

Figure 4 shows the results of experiments carried out in a hydraulic tray at a scale model 1:40. The section of the river bed, after the flow leaves the mountains, is significantly narrowed to the width of a stable river bed, calculated according to the method of S. T. Altunin [14].

Figure 4. Investigation of the flow control scheme on the section of the Bystritsa Solotvinskaya river near the village of Yablonka.
The grions installed on the model were combined structures, that is, each of them consisted of two parts – a part without openings adjacent to the shore and oriented normally to it, as well as a low flooded part oriented at an angle of 45 degrees towards the stream. The height of the structure part without openings was selected taking into account the height of the flood of one percent security and some reserve above this level, and the low flooded semi-dam had a height equal to 0.25 of the depth with an average minimum water level in the river bed. With such parameters, the flooded parts of these structures provided the best interception and transport of sediments in the flood from the transit flow towards the inter-lunar space [15].

The experiments carried out above showed that a dynamic balance of sediments was established on the model. A stable river bed of a parabolic shape is formed between the heads of the bun, the sediment bar slowly shifts downstream and the inter-bun spaces are filled with sediments.

To visualize the processes of sediment transport and evaluate the effectiveness of the structures described above, it is also possible to use modern control methods based on the use of photo and video recording with the use of subsequent software processing of the obtained data [16, 17, 18].

4. Conclusions

As a result of the experimental data analysis, as well as model calculations, a technique was developed that allows calculating the deformations of the bottom and shores, and also forming a flow organization scheme, which, due to an increase of the velocities in a certain section of the river bed, where sediments and stream wandering are especially undesirable, ensures the transfer of sediment to more remote near-shore areas, up to the high sea.

The creation of systems of flooded buns (semi-dams) can significantly improve water quality, eliminate sediment deposition zones, blooming and other negative consequences of stagnant phenomena on the near-shore zones. Taking into account the real hydrodynamics of rivers and reservoirs, the river bed deformation processes, further it is advisable to develop the problem of alluvial sediment reformation and the development of small rivers near-shore zones, while solving the equations of sediment turbulent transport for a two-phase fluid, as was done in the studies [19, 20].

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