A Method for Determining the Movement Speed of Suspended Particles by a Water Flow and Its Application in Studies of Sea Estuaries of Rivers

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Abstract. The article discusses the developed technical and methodological tools designed to study the process of sediment transport. A brief description of the device is given, which makes it possible to obtain the data on the movement speed of suspended particles using video recording. The technique of carrying out field experiments is described, on the example of studying the sea estuaries of rivers. The field measurements results are presented. The developed method makes it possible to determine the movement speed of suspended particles, as well as to describe the fine structure of the flow, which is necessary to study the mechanisms of erosion, accumulation and sediments transport.

1. Introduction

Active economic activity in the coastal sea zone leads to the intensification of various technogenic processes, which has a negative impact on the environment. According to this, increasing attention has been given to environmental monitoring, which is necessary to organize the effective environmental protection measures. One of the topical areas of research in this area is the study of hydrological processes in sea estuaries of rivers. Hydrodynamic and morphological structure, properties of water masses formed by mixing river and sea waters determine the course of various natural processes not only in the mouth area, but also outside it [1]. Currently, river mouths are of great scientific and applied interest. In many ways, it is associated with the use of the resource potential of these areas and with the need for their conservation and protection from pollution, since river estuaries are the location of many large ports. At the same time, the combination of natural and anthropogenic factors that determine the evolution of estuarine areas implies additional difficulties in the study of such objects [2]. In accordance with this, it is necessary to create new technical means and methods for the implementation of these tasks.

One of the environmental monitoring tasks is to study the erosion mechanisms, accumulation and sediments transport. Understanding of these processes in the estuarine area of rivers is necessary for the organization of effective coastal protection measures. This article discusses the developed method for determining the movement speed of suspended particles in a water flow, based on the acquisition and software processing of video images, which makes it possible to obtain data on the water flow dynamics. There are a number of methods and instruments for determining the flow rate [3, 4, 5, 6, 7]. In the study of rivers, current-meters are mainly used [8, 9]. These devices, as a rule, make it possible
to determine the horizontal component of the flow velocity at a given horizon, at a certain point. However, in order to study the above-mentioned processes, it is necessary to have a more detailed understanding of the particles motion in space, in particular in the bottom area where the processes of the bottom material disturbance and sedimentation take place. The existing technical means do not allow for the full availability of such data. In accordance with this, a measuring complex has been developed [10, 11], the operation of which is based on the use of the PIV method [12, 13, 14]. The application of this method makes it possible to obtain the spatial distributions of flow velocities [15, 16, 17], which are necessary for solving various problems associated with mass transfer, erosion and silting of water areas.

The purpose of this work is to show the developed method capabilities for determining the movement speed of suspended particles under the study of sea estuaries.

2. Hardware and software development

The developed measuring complex "Flow Visualizer", the diagram of which is shown in Figure 1, consists of several functional units:

1. Backlight unit, which is a waterproof LED module with a power of 20W, with a slit diaphragm to reduce parasitic illumination.

2. The registration unit, which includes a digital video camera [18, 19], operating in "slow motion" mode and providing the process registration at a maximum speed of 240 fps.

3. Positioning unit, consisting of a U-shaped rod with plates attached to it. The task of this unit is to orient the complex in the flow direction.

4. Data processing unit. Adapted software for obtaining current velocity fields. Its diagram is shown in Figure 1.

![Figure 1. The Measuring Complex Diagram.](image)

To carry out research in river mouths, in order to study the sediment transport processes, a methodology and recommendations were developed to perform measurements using this complex. According to this technique, experimental observations should include:

− determination of the sediment movement rate in the alinement;
− constructing a flow velocity distribution for the bottom layer to investigate small-scale turbulent processes;
− studying the dynamics of water masses in the mouth zone (determination of the period, frequency of the reciprocating movement of water, changes in the flow rate in time).
The selection of the alignments is based on reconnaissance site surveys and remote satellite imagery. Further, the alignments and stations marking is carried out, as well as surveying work. The network of stations and alignments should include: the mouth vertex, the lower boundary of the river mouth section (lower delta boundary), and the mouth nearshore.

The stations are selected according to the following method:
- for the alignments with a width of more than 50 m, the measurements are carried out at three stations (in the middle of the alignment and at one station at a distance of 10 m from the left and right banks);
- for the alignments from 10 to 50 m, measurements are performed at two stations (the distance from the right and left banks is chosen based on 1/3 of the section width);
- for the alignments less than 10 m – at one station in the middle of the alignment.

Horizon assignment methodology:
- for stations with a depth of 0.5 to 1 m, 1 horizon is performed (in the presence of strong algae fouling – a surface layer, with no fouling – a bottom layer, to study the disturbance processes);
- for stations with a depth of 1 to 3 m, 3 horizons are performed (surface, middle of depth at the station, bottom layer).

After performing the accompanying measurements (temperature, salinity, turbidity, flow rate using a current-meter), stations with maximum and minimum parameter values are selected and further experiments are carried out at these stations using the developed complex.

As an example, Figure 2 shows a diagram of slats and stations, compiled on the basis of the above-described methodology, for the study of sedimentation and sediment transport processes at the mouth of the River Black in Sevastopol.

![Figure 2](image)

**Figure 2.** Diagram of Stations for Measurements by the Flow Visualizer Complex at the Mouth of the River Black.

3. **Verification of the results**

The developed complex was used in expeditionary work at the sea mouth of the River Black in the area of river and sea water interaction. Based on the results of field experiments, spatial distributions of flow rates were obtained, necessary for solving various problems related to mass exchange, erosion and siltation of water areas. As an example, Figure 3 shows images of the "instantaneous" field of flow rate on three horizons (surface, middle and bottom layer) obtained during expeditionary research. Measurements were made in the area of mixing sea and river water, which is characterized by an unstable flow structure. The highest velocity values were 0.4 m/s, in addition, the current periodically...
changed direction to the opposite, which was recorded when making measurements in the middle layer, while the average flow rate was 0.13 m/s. The bottom layer is characterized by the presence of turbulent processes that were visualized by using the developed complex.

![Image of flow rate field](image)

**Figure 3.** Flow Rate Field in the Surface (a), Middle (b) and Bottom (c) Layer.

During the expedition, the experiments were carried out in accordance with the developed procedure described above. Speed measurements were carried out in different alignments and horizons at the mouth of the River Black. The velocity profiles necessary for the flow dynamics studying were obtained. For example, Figure 4 shows the movement speed distribution of the sediment suspension in one of the alignments.

In the indicated alignment, the flow, at a rate of 0.01 to 0.4 m/s, was multidirectional in depth. Currents in the direction "from the river" in the middle layer along the alignment in the bottom layer at stations 4 and 14 dominated. In this alignment, in conditions of low-water flow of the river, there was an interaction of two main flows: the direct direction, due to the flow of the river and the reverse flow, reversible, due to the supply of saltier water from the bay to the estuary section of the river.

Mixing of water masses led to unstable flow structure and local agitation of sediments in the bottom region.

![Image of speed distribution](image)

**Figure 4.** Histogram of the distribution of the average flow rate of the water flow.
At the same time, measurements were also carried out using standard means, namely, a current-meter as part of the “Condor” measuring complex [20]. The average values of the flow rate obtained by both instruments match well, the discrepancies do not exceed 11%. This confirms the reliability and sufficiently high accuracy of measurements using the created complex.

4. Conclusions
Thus, the analysis of the expeditionary studies results obtained using the developed method made it possible to develop methodological approaches when assessing the current state of a water body and the informative parameters of its state using the visualization method. The data based on the created method were obtained on the movement speed of suspended sediments in the estuary zone of the River Black. Comparison with the data obtained by standard technical means, namely the a current-meter, which is part of the “Condor” measuring complex, showed good convergence.

5. References
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