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INVESTIGATING CURRENTS, FLOW VELOCITIES, AND RIVERBED MORPHOLOGY - AN ADCP-CENTRIC APPROACH TO UNDERSTANDING HYDRODYNAMICS AND EROSION PATTERNS

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Abstract

The sediment movement on a river plays a crucial role in safe navigation and economic activities on navigable channels. Environmental changes in time are given by the morphological characteristics of the riverbed during seasonal water variation on the Danube River. This study presents a comprehensive assessment of the Danube River`s velocity and current characteristics based on Acoustic Doppler Current Profiler measurements. The correlation between flow velocities and depths helps to understand the factors that influence sediment patterns and provides insights into the sustainable management of the river system. The study was conducted along a 71-kilometer length of the Sulina Branch from the Danube River, where ADCP measurements were collected at multiple locations and over periods. The data collected included water depth, flow velocity, and current direction. By clustering the column depth cell velocities it revealed significant spatial and temporal variations in the velocity and current patterns, influenced by factors such as river morphology, discharge, and seasonal changes.

***Key words**: ADCP survey, currents direction, Danube discharge, hydro-morphology, water flow velocities.*

INTRODUCTION

The Danube River divides into 2 branches at Patlageanca Village. Chilia - the first branch, flows in the North-East direction. The second one flows to the East, and after at, the Tulcea city is divided into two other branches, Sulina respectively Sfantu Gheorghe (Figure 1).

The Sulina branch is the main waterway of Romania, for the ships with a maximum 7.01 m ± 10-15 cm draught, from the Black Sea up to Braila city (Cociasu et al., 1996; Giosan et al., 2006; Kuhl, 1891).

The rectification of the Sulina arm was carried out during the 1868-1902 period, shortened this branch by about 25% (83.8 km before the cut-offs and only 69 km today) (Cociasu et al., 1996; Giosan et al., 2006; Kuhl, 1891; Panin & Jipa, 1998).

This cut-off program induced a redistribution of water and sediment discharge among the delta distributaries.

The Sulina discharge increased from 7-9% up to 16-17% in 1921 and to about 18-20% of the total Danube discharge at present (Panin & Jipa, 1998).

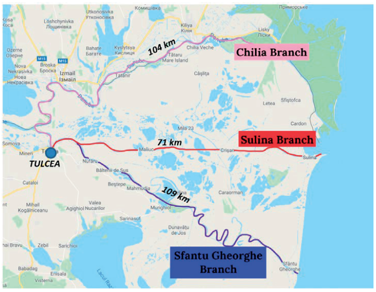

Figure 1. The main branches of the Danube River

The Sulina Channel, one of the branches of the Danube River, has specific dimensions: a length of 71 kilometers, a maximum width of 50 meters, a maximum depth of 18 meters, and a minimum depth of 7.32 meters (Banescu et al., 2020a). This arm of the Danube has been regulated and channelized, allowing for maritime navigation of seagoing vessels with a draft of up to 7 meters. The maintenance and management of this waterway fall under the responsibility of the Lower Danube River Administration (AFDJ), based in Galati, the largest city along the Romanian stretch of the Danube. It is noteworthy that the Sulina Channel, also referred to as the Sulina arm, is the shortest and most direct branch of the Danube, flowing directly into the Black Sea near the town of Sulina. Sulina is the easternmost settlement within the European Community.

The Sulina branch carries a significant amount of sediment, particularly during flood events, which can lead to the deposition and accumulation of sediments Danube Delta. Sediment transport and deposition in the Sulina Channel can affect water depths and navigation channels, necessitating periodic dredging operations to maintain the required depths for maritime traffic. The management of sediment transport and dredging activities in the Sulina Channel is crucial for maintaining navigation and preventing potential blockages or shallow areas that could hinder vessel movement. Monitoring and modeling of sediment transport patterns, as well as implementing appropriate sediment management strategies, are essential for the sustainable management of the Sulina Channel and the Danube Delta region.

At the same time, the sediment deposition influences the stock of heavy metals on the Danube River (Popa et al., 2018; Teodorof et al., 2021). According to Lazăr (2024), the heavy metals from sediments and water in the Danube River are ingested directly by biota, especially in the *Alosa immaculata* fish. According to the study conducted by Burada (2015), hydro-morphological parameters are important for identifying the areas where the speed of flow currents decreases because sedimentation increases in these areas, and with it the accumulation of pollutants (heavy metals) also occurs. This suggests that the morphology of the riverbed and the hydrodynamics of the river are key factors in identifying areas vulnerable to contamination, and can be achieved by accurate ADCP measurements.

The present study aims to investigate the relationship between hydro-morphological parameters surveyed on the Sulina branch from the Danube River. The physical characteristics and dynamic parameters help to understand the patterns of erosion, underwater forms, and turbulence in the study area.

STUDY AREA

The study area is focused on the Sulina branch of the Danube River. There are 6 points of observation. Each of them is located downstream of Partizani, Maliuc, Gorgova, Crisan, and Sulina villages (Figure 2), and one at an intermediate point between Crisan and Sulina.

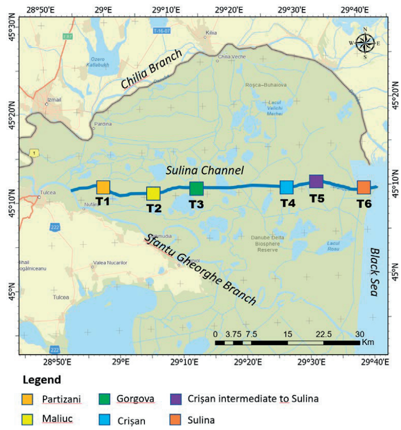

Figure 2. Study area map located on the Sulina navigable channel from the Danube Delta area

The points labeled T1 through T6 mark specific cross-sections where Acoustic Doppler Current Profiler (ADCP) data are collected. These six cross-sections are conveniently located along one of the main tributaries of the Danube River, the Sulina arm.

The corresponding ADCP cross-sections measured in July 2023 and August 2023 from this transects are crucial to understanding how riverine discharge, velocity profiles, and sediment deposition are influenced across the river continuum, particularly in the tidal junction near the mouth of the river (Banescu et al., 2020b; Pomázi & Baranya, 2025).

MATERIALS AND METHODS

To better understand the flow dynamics of the Sulina channel, which is an arm supposed to hydrotechnical development works, it is important to measure the hydro-morphological parameters in different hydrological periods of the channel.

Thus, we can assess whether sediments are transported from one section to another. Along with the transport of sediments, the minor channel bed is also modified, but also their deposition by favouring the increase in the surface area of the Danube Delta.

To obtain a detailed picture of the hydro-morphological parameters on the Sulina branch, several measurement campaigns were carried out. These aimed to evaluate the spatial and temporal variability of current speeds and flows, essential information for determining the sediment transport regime. Within these campaigns, ADCP (Acoustic Doppler Current Profiler) technology was used, a modern instrument for measuring water current speeds in three dimensions, at different depths (Figure 3). The device used was the RiverSurveyor M9 model produced by SonTek, a high-performance equipment designed specifically for river measurements.

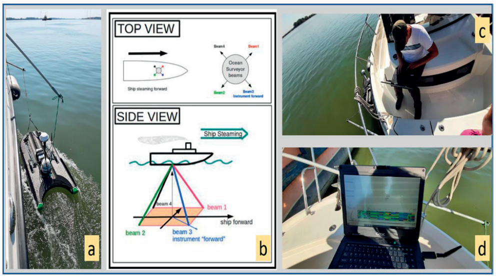

Figure 3. The Sontek M9 ADCP work principle: a - mounting on a moving boat; b - beam spread principle (Deogade et al., 2023); c, d - main setting applying and real-time display data

The ADCP works based on the Doppler effect: it emits sound waves in the water, which, when reflected from suspended particles, change their frequency according to the relative motion of these particles. By analyzing this frequency change, the instrument can calculate the speed of the current in different layers of the water column, according to equation 1 (Liu et al., 2024).

$$v = (\Delta f \times c) / (2 \times f_0 \times cos(\theta)) \quad (1)$$

where:

- v represents particle (water current) velocity in the direction of the sound beam [m/s];
- Δf represents Doppler frequency difference (f_r - f_0), i.e. the difference between speed of sound in water (approximately 1500 m/s);
- c represents frequency of the signal emitted by the ADCP [Hz];
- θ - angle between the acoustic beam and the vertical direction.

In addition to the basic hydromorphological parameters measured, it is important to determine the energy in each flow section. The calculation of the current energy (or kinetic energy of flowing water) in a section measured with an ADCP is based on the application of fluid mechanics principles, in particular the formula for the kinetic energy of a volume of water moving at a given speed. Equation 2 represents the calculation of the energy flow on a river cross-section measured with ADCP equipment (Guseva et al., 2021).

$$E = \frac{1}{2} \cdot \rho \cdot Q \cdot v^2 \quad (2)$$

where:

- E represents current energy (mechanical power) [W – watts, i.e. J/s];
- ρ represents water density [kg/m³] (usually ≈ 1000 kg/m³ for fresh water);
- Q represents water volume flow or disgharge [m³/s], obtained directly from ADCP data;
- v represents average current velocity [m/s], measured by ADCP.

RESULTS AND DISCUSSIONS

The monitoring of sediment transport comprises suspended sediments, a well as bedload. To understand, to assess, and to give potential solutions for sediment-related problems in the Danube River, especially on the Sulina Branch, the amount of transported sediments, varying both in time and space, has to be known. For this purpose, ADCP cross-sections are measured during two different campaigns, in July and August 2023. The results of ADCP cross-sections at T1 to T6 monitoring points are represented in Figure 4.

The ADCP measurement from both survey campaigns shows a well-distributed water velocity in the middle of the cross-section. The water velocity decreases near the left and right banks in all cases.

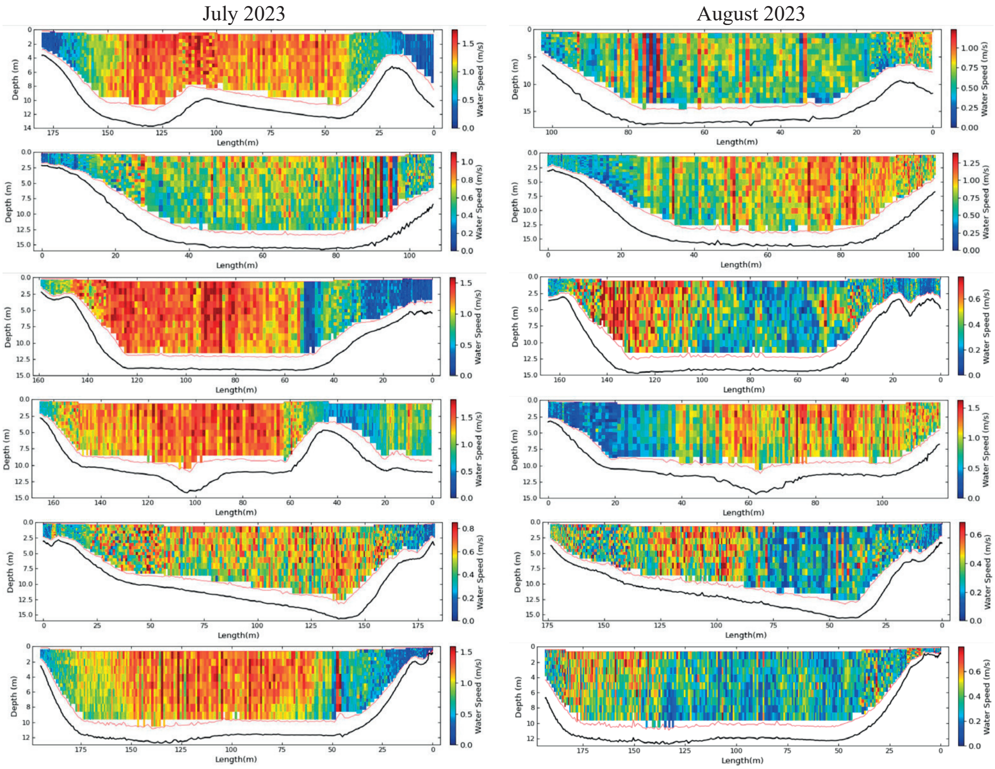

Figure 4. The ADCP velocity representation on the T1 to T6 cross-section

The maximum of 1.13 m/s water velocity was recorded at T1 section in July 2023, and 0.988 m/s at T2 section in the August campaign.

Figures 5 and 6 highlight a vector representation of the flow currents in the cross-sections T1-T6. The orientation or angle of inclination of the black vectors indicates the flow currents' direction, and the length of the vectors shows the intensity of the flow currents.

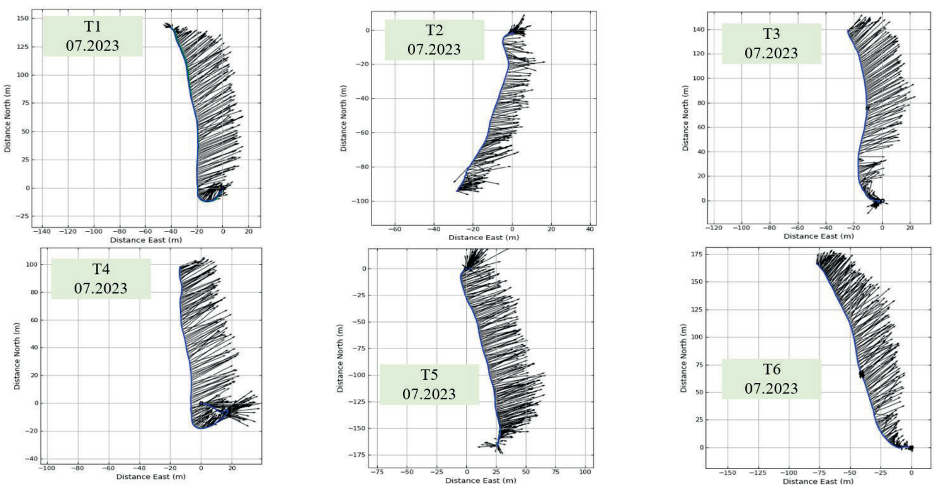

Figure 5. Comparison of flow patterns, directions, and intensities of currents for the July survey across T1-T6 transects

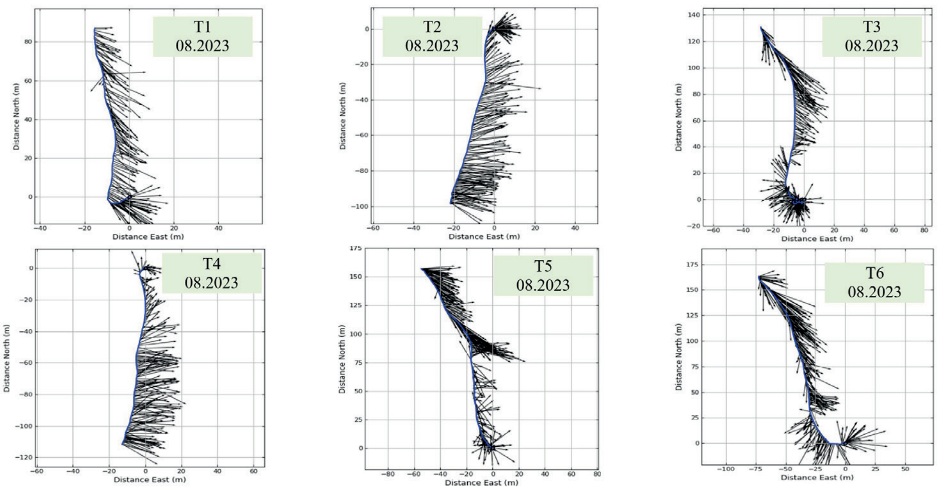

Figure 6. Comparison of flow patterns, directions, and intensities of currents for the August survey across T1-T6 transects

If we analyse the data in the context of the riverbed morphology of the Sulina channel, we can mention that in the sections T3 and T4, we have a series of eddy currents that favor the engagement of sediments in the water suspension and their transport from upstream to downstream.

Figure 7 shows a decrease in water velocity downstream of the Sulina channel. Compared to discharges, it can be mentioned that these parameters are influenced directly by water velocity.

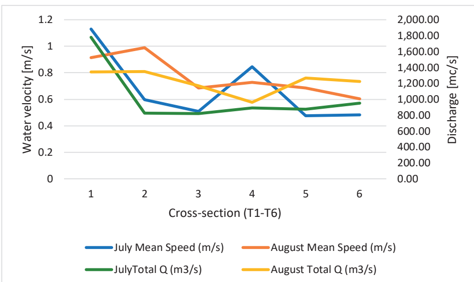

Figure 7. The water velocity average values in each cross-section are compared to the total discharge at two different survey times

The calculated energy values increase from upstream to downstream of the river, and it is higher for the August survey campaign when the discharges are also higher (Figure 8).

In the assumption that the sediment suspended concentration is calculated by Equation 3, the total suspended sediment concentration (SSC) on each vertical profile from each cross-section was calculated (Boldt, 2015).

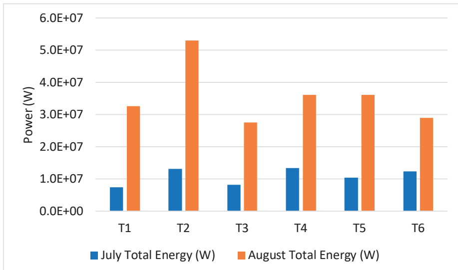

Figure 8. The total energy power of T1 to T6 cross-section

$$log_{10}(SSC) = log_{10}(a \cdot 10^{b \cdot DB}) \quad (3)$$

The a=0.005, and b=0.01 are the coefficients averaged from different scientific sources, related to Danube River SSC values. According to Baranya and Józsa (2013), in the Danube River, a 125 mg/l average SSC was measured. The SSC estimated from the SWAT method in the Danube River Basin by Vigiak (2017) was about 80 mg/l.

Between the T1 and T6 transects in July 2023, significant variations in the SSC values are given across transect length (Figure 9).

In the T1, T2, and T5 sections, where the currents are stronger, the average SSC is: 53.5 mg/l, 69.7 mg/l, and 50.8 mg/l, respectively. This suggests a higher transport of sediment from one section to another.

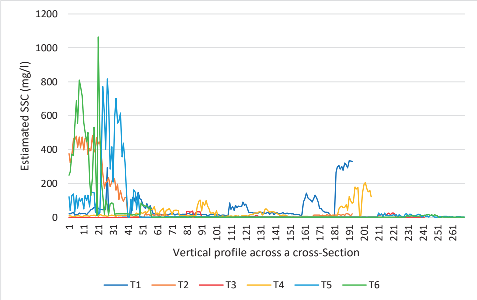

Figure 9. Suspended sediment concentration estimation based on backscatter signal (dB) on the July 2023 survey

In section T6, with the maximum value of SSC concentrations of 1064.59 mg/l, it is demonstrated that all sediments are transported downstream to the mouth of the Black Sea, more precisely, the "Bara Sulina" area.

Analyzing Figure 10, we observe an increase in the SSC value for transects T5 and T6.

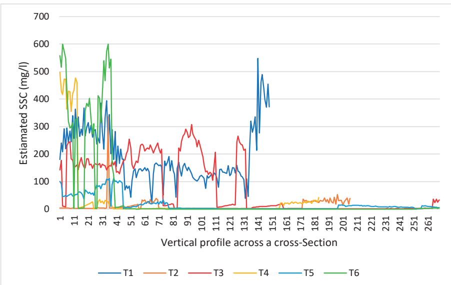

Figure 10. Suspended sediment concentration estimation based on backscatter signal (dB) on the August 2023 survey

These only confirm the fact that the sediments are transported in large quantities downstream in the area of Sulina, where the intensity of the current gradually decreases and their storage takes place. In section T1, the highest mean value of the EFS of 193.2 mg/l and a high standard deviation (100.1 mg/l) were estimated. This denotes the fact that the hydrodynamic conditions in this area are varied and with strong suspended sediment entrainment. In the T6 section, the maximum of 941.5 mg/l suggests the presence of intense sedimentary accumulation events.

CONCLUSIONS

The research study carried out for the monitoring of flow currents by the ADCP method helps to determine the phenomenon of sediment transport in fluvial environments.

The high values of the SSC concentration in July 2023 (1064.5 mg/l) and August 2023 (941.4 mg/l) in section T6 show the presence of sediment transport processes towards the confluence with the Black Sea, and their deposition in the "Bara Sulina" area.

The hydrodynamic parameter E (energy), increased in value especially in August 2023, in the upstream sections T1 (3.3×10^7 W) and T2 (5.3×10^7 W), and decreased in value in the T6 section in both months, indicates the erosion trend from upstream to downstream.

Applying the method of estimating the SSC from the backscattering of the ADCP signal, we concluded that the largest amounts of sediments are in the downstream area of the Sulina channel.

The effect of sediment transport from upstream to downstream only increases the clogging of the Sulina channel at the confluence with the Black Sea. Thus, continuous monitoring and investigation of currents and flow velocities by the ADCP method is mandatory. The ADCP and SSC estimation method offers an integrated approach to measuring hydro-morphological parameters and correlating with sediment transport processes, helping to plan hydrotechnical maintenance works and emergency interventions on the maritime-river navigation infrastructure in the respective area.

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