Estimation of SSC in Rivers Using ADCP Backscatter Data

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Abstract
For more than two decades, Acoustic Doppler Current Profilers (ADCPs) have been in common use measuring current profiles. In recent years, the acoustic sensors such as ADCP have become a more widely used in means of estimating suspended solids. Plenty of studies have indicated that there is a strong relation between acoustic backscatter intensity and Suspended Sediment Concentrations (SSC). Conventional measurement techniques for collecting of data on SSC are real challenge considering the time and effort to collect all necessary data. Furthermore, it is often unfeasible to perform measurements during the floods, which leads to a lack of data in this range of flow. For those reasons, there is a need to establish a contemporary and sustainable methods in sediment monitoring systems which will enable continuous data acquisition. Acoustic sensors such as ADCPs offer a lot of advantages over traditional methods in SSC monitoring. The results in utilization of ADCP for suspended sediment monitoring will be presented in this paper, as well as the reliability assessment relative to the data collected using conventional methods.

Keywords
SSC; ADCP; sonar equation; correlation

INTRODUCTION

Sediment regime is very significant factor in case of river dams, due to the inevitability of sedimentation process in reservoirs and consequential reduction of its active storage. To provide an assessment of the sediment transport and deposition processes in the Iron Gate Reservoir, located on the Lower Danube in Serbia, a monitoring program has initiated in 1974 by the Jaroslav Černi Water Institute (JCWI) and it is still going on. The annual monitoring program consists in daily observations of suspended sediment concentrations as well as periodic field measurements of water and sediment discharge with conventional measurement techniques.

Conventional measurement techniques for collecting of data on SSC are real challenge considering the time and effort to collect all necessary data. Furthermore, it is often unfeasible to perform measurements during the floods, which leads to a lack of data in this range of flow. For those reasons, there is a need to establish a contemporary and sustainable methods in sediment monitoring systems which will enable continuous data acquisition. Instead of conventional monitoring methods, optical and acoustic backscatter sensors (OBS and ABS) are widely used in sediment monitoring programs all around the world. Since the measurement of flow velocity with ADCP is based on particles velocity in river flow, it can be assumed there is a correlation between the acoustic backscatter intensities and SSC. This paper will present results of sediment survey within the Project area from 2020, using both conventional and ADCP methods.

THEORY

ADCPs are primarily developed to measure current velocity profiles. ADCP initiate a Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from sediment particles in the water. The acoustic signals reflected from suspended sediment particles also provides information about the SSC. This information is measured in the form of reflection intensity, also referred to as backscatter. To compensate backscatter data for acoustic loss, it is necessary to add the acoustic loss terms to the converted backscatter. The loss terms are acoustic spreading, water absorption and particle attenuation. Acoustic spreading is simply a geometric term derived from the conical shape of the acoustic beams. Water absorption is caused by molecular transfer of acoustic energy to heat. It is a function of temperature, frequency, salinity, depth, speed of sound and pH (François and Garrison, 1982 a,b). Salinity can be derived from conductivity, temperature and depth (UNESCO, 1981). Particle attenuation is the spreading and absorption of acoustic energy by particles in the water. The Rayleigh scattering law applies for particles that are small compared to the acoustic wave length (Rayleigh, 1945). Particle attenuation is a function of temperature, frequency, speed of sound, kinematic viscosity of water (calculated from Van Rijn expression, Van Rijn, 1993), water density, sediment density, grain size distribution and SSC (Urick, 1983).

Using the ADCP backscatter data in purpose of SSC measurements requires the additional processing of acoustic information. In this paper, ADCP backscatter data processing is based on the principle of sonar equation described by Deines (Deines, 1999).

The idea is to determine the so-called absolute backscatter, that can subsequently be converted to SSC by means of calibration with reference to SSC data from water samples. This could be done according to the following equation:

$$\log_{10}(SSC) = A \times I + B \qquad (1)$$

In which I is the absolute backscatter in dB, and A and B are constants (conversion coefficients). By assuming that there is a linear relationship between I and $\log_{10}(SSC)$, coefficients A and B can be derived from linear regression. This requires the availability of reference concentrations from water samples taken during the measurement (Figure 1).

Estimated correlation can be then used to convert all data from ADCP across the entire cross-section into SSC values.

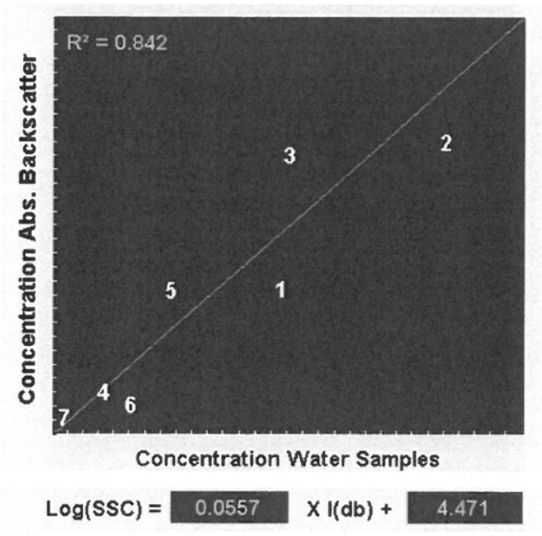


Figure 1. Correlation plot with water samples and conversion coefficients.

DATA COLLECTION

Sediment sampling
Locations of monitoring profiles where sediment measurements were done are presented on the map in the Figure 2.

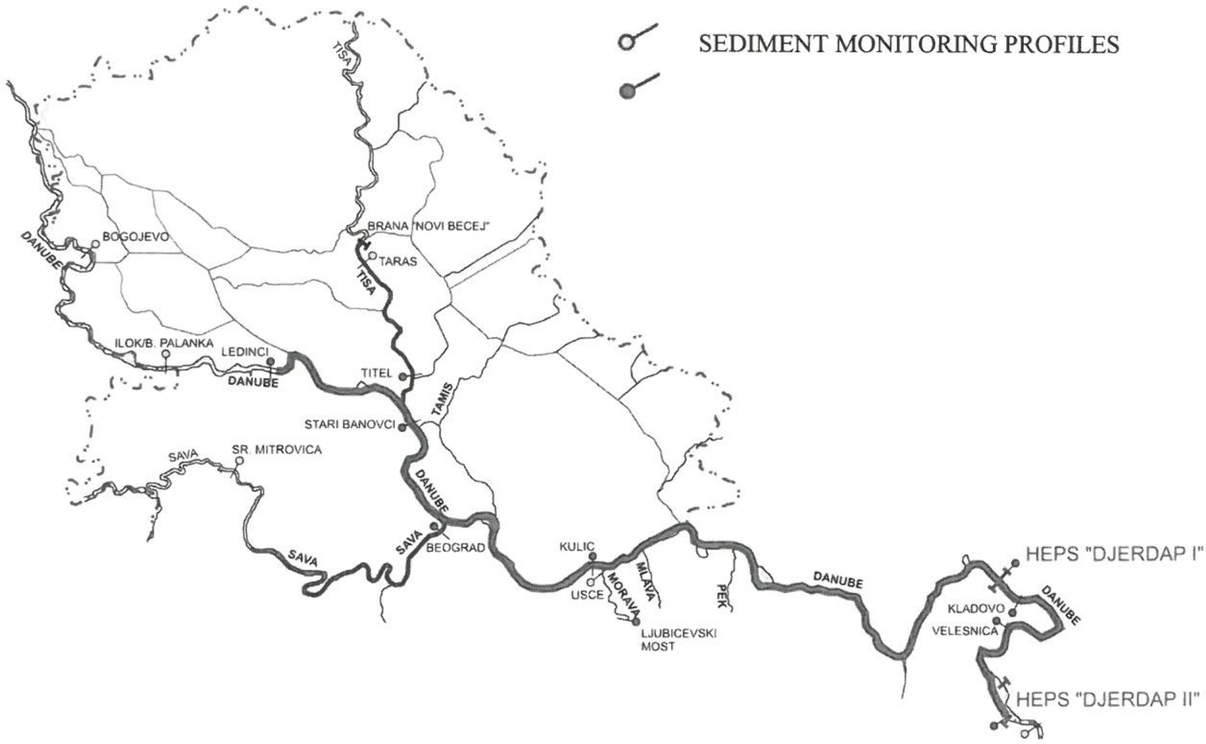


Figure 2. Monitoring profiles within the Iron Gate Reservoir.

On each monitoring profile suspended sediment sampling was done in nine points distributed in the river cross section as presented in the Figure 3.

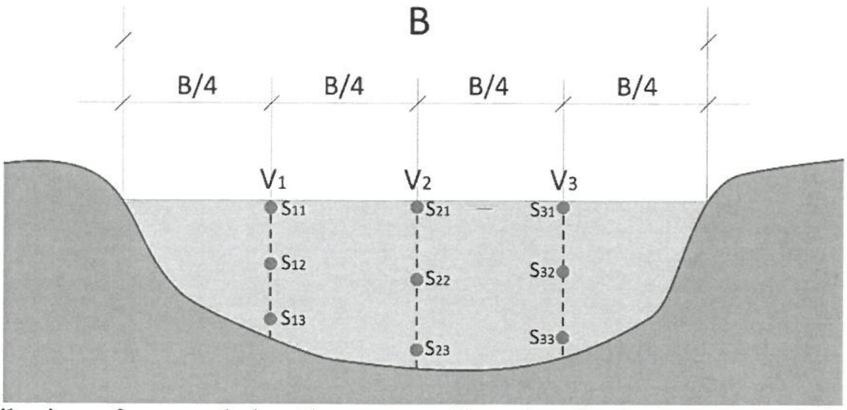


Figure 3. Distribution of suspended sediment sampling sites in river cross section (V1 is near left bank).

Samples of suspended sediment were collected using pump sampler, 10-litre samples at each point. The measurement device of the pump sampling is a pump with a suction pipe connected to the torpedo (sampler) and a weight which helps to stabilize the sampler in the flow (Figure 4).

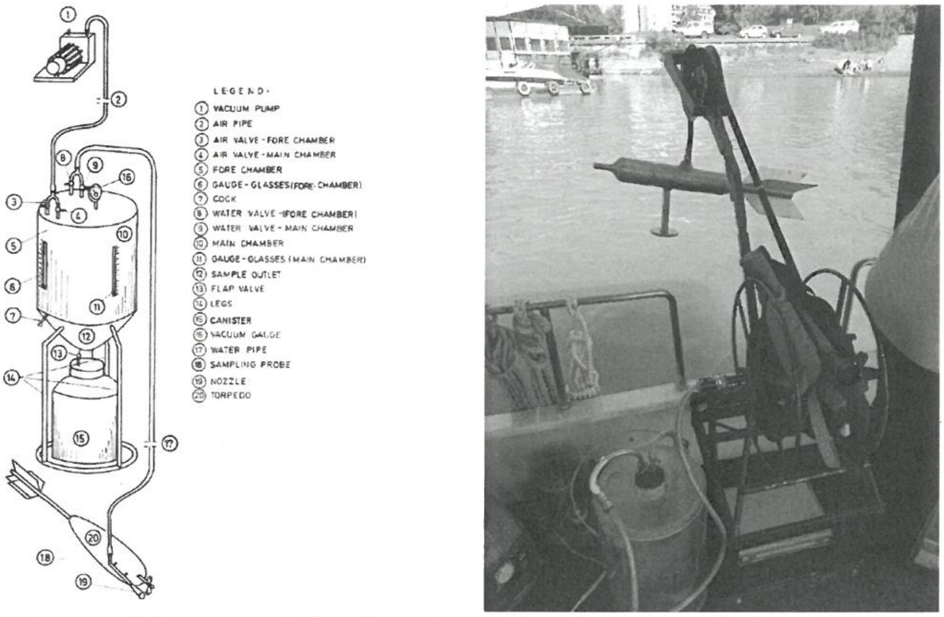


Figure 4. Devices used for suspended sediment sampling (pump sampler).

During the measurement, the sampler is lowered from a boat at the vertical to the depth required. In this depth, the pump starts to vacuum water and suspended sediment through the sampler and the chamber starts to fill. The pump efficiency must be selected so that the sampling could be done from each depth and the flow velocities near the nozzle of the sampler do not differ from the flow velocity in that depth of the vertical. If the difference is too big, the suspended sediment concentration (SSC) would vary depending on the grain size. SSC is higher when the entering velocity is lower than the flow velocity.

Laboratory

Samples of suspended and bottom sediments were labelled and transported to the JCWI Sediment laboratory for processing. The laboratory analysis contains SSC measurement and particle size distribution (PSD) analysis as well. In order to determine the SSC, the evaporation method is used on the collected samples. After the sediment settling process (at least a few days long), 1-1.5 l of concentrated sediment is decanted and transported into the sediment laboratory. After 24 hours of sediment settling, a sample of 100 ml of sediment is taken. The settling process is repeated for another 24 hours, and then all of the sediment dried on 105 °C for 4 hours and weighed. The sediment concentration is calculated on the basis of known volume of sample and the weight of sediment.

For the PSD analysis a sedimentation instrument and a sieving instrument is used. Grain size of coarse particles were measured on sieves, while grain-size of smaller particles was measured by fraction-meter (for particle diameter > 0.063 mm) and the pipette-method (for smaller particles). Both methods determine the particle fall velocity (ω).

ADCP data

Acoustic backscatter data were collected with the RDI 600 kHz ADCP. The ADCP was mounted to the boat and lowered so that the transducers were 20 cm below the water surface. The boat heading, velocity and location were recorded with a Hemisphere vector GPS system. Prior to collecting water samples, two ADCP survey lines were run along the monitoring profile (one in each direction) to collect discharge, average velocity, and acoustic backscatter. The boat is then moved to each water sampling location along the measurement cross-section and recorded ADCP data simultaneously while water samples were collected (Figure 5).

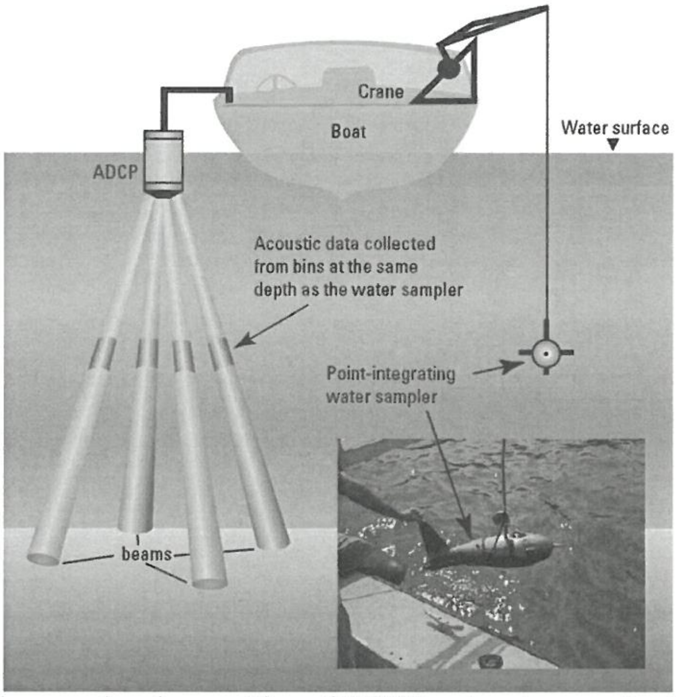


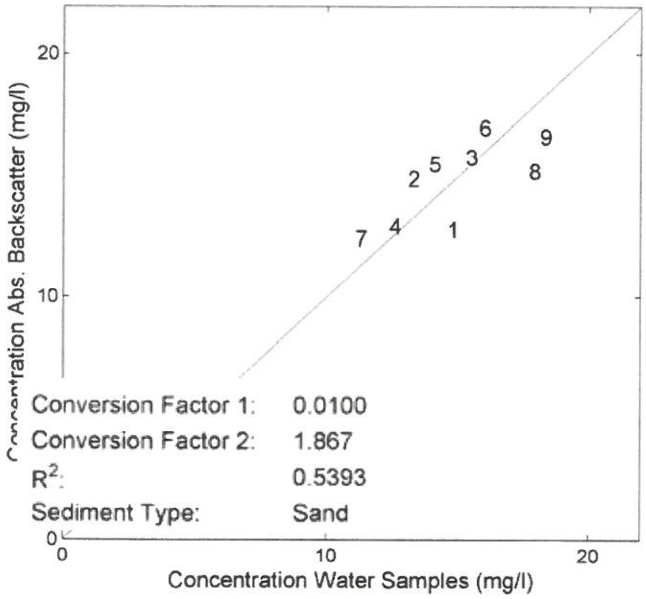
Figure 5. Schematic diagram showing position of ADCP and water sampler for ADCP calibration.

RESULTS

ViSea STAR software had been used to assess suspended sediment concentrations in the cross sections on measurement sites. The Sediment Transport Analysis Routine (STAR) is a stand-alone application for post-processing ADCP output in order to compute suspended sediment concentration and flux. The only input required by the STAR are ADCP output files and suspended sediment concentrations from water samples.

The procedure in STAR to determine coefficients A and B from Eq. 1, starts with calculating the acoustic backscatter and sediment concentrations using default values for these coefficients (A=0.04 and B=4). These backscatter values are then compared to the reference concentrations from the water samples. The new conversion coefficients are obtained through linear regression. By applying these new conversion coefficients on the dataset, new values for the acoustic backscatter and sediment concentrations from the ADCP are obtained. The result of this can be seen in the correlation plot in Figure 6 for one of the monitoring profiles within the Project area.

Main advantage of using ADCP is the fact that water samples can only provide information at a specific point of the water column, while ADCP can provide data through the entire cross-section (Figure 7).



SSC Sample	SSC ADCP
15	13
13	15
16	16
13	13
14	16
16	17
11	12
18	15
18	17

Figure 6. Correlation plot with conversion coefficients between SSC obtained from water samples and ADCP data.

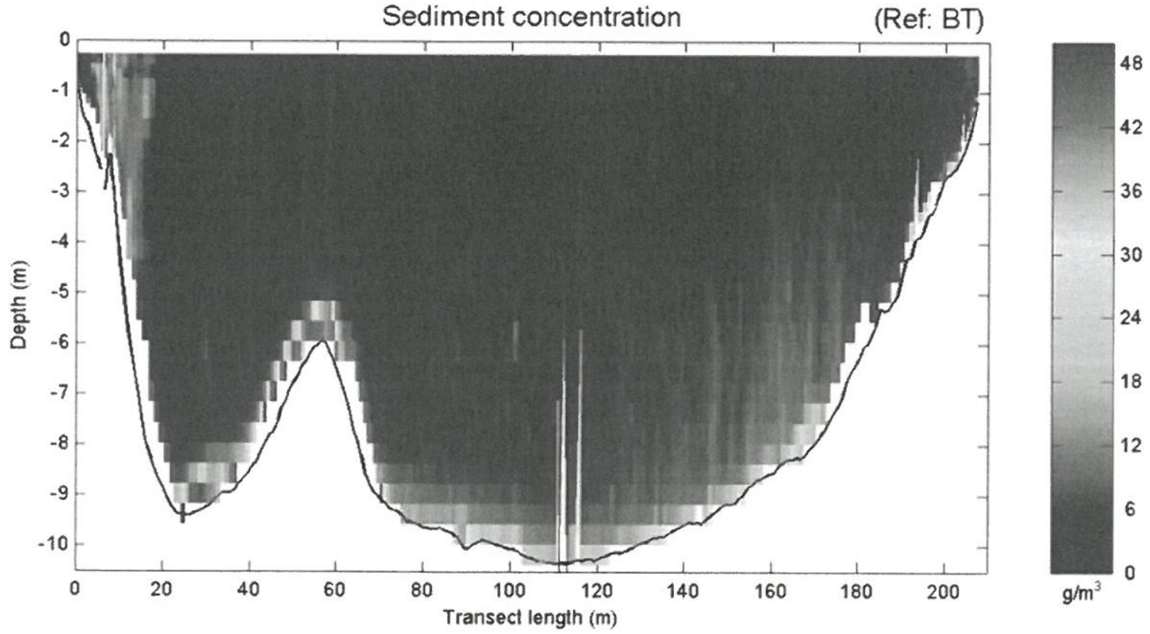
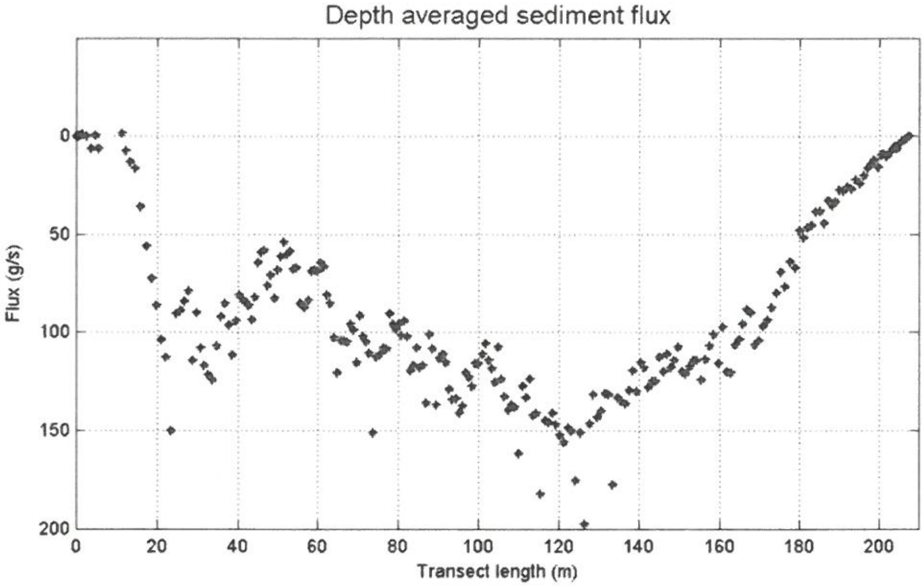


Figure 7. SSC distribution in the cross-section obtained from correlation between water samples and ADCP data.

Depth averaged sediment flux distribution in the cross-section obtained from ADCP data is presented in Figure 8. Total suspended sediment load estimated from ADCP data is 20.23 kg/s, while total load estimated from water samples is 19.5 kg/s.



Flux in kg/s				Flow area in m^2	
F_{top} :	0.61	F_{tot} :	20.23	ADCP :	1579.7
F_{mid} :	16.36			Total :	1614.0
F_{bot} :	3.26			% meas:	98

Figure 8. Depth averaged sediment flux distribution in the cross-section obtained from ADCP data.

CONCLUSION

An acoustic backscatter method was applied at monitoring profiles along Iron Gate Reservoir to estimate suspended sediment concentration. The estimation methodology was based on the modified sonar equation. The two immeasurable constants in the sonar equation were calculated though a calibration process using intensity of acoustic signals from ADCP. These constants are then used to estimate SSC values from acoustic signals strength recorded by ADCP. Verification of this results is obtained by comparing the ADCP-derived SSC with SSC values derived from water samples analysis. Error of comparison between ADCP and direct measurement was not more than 3 mg/L. The correlation coefficient was found to be 0,55. The acoustic results confirmed a comparable estimation performance with respect to those given by direct measurement of SSC. Total sediment load in cross-section estimated from ADCP data is 20.23 kg/s, while total load estimated from water samples is 19.5 kg/s.

The analysis and calibration procedures indicate that acoustic signals from ADCP provide reasonable vertical distributions of the SSC. Although the ADCP-based SSC slightly differs from water samples SSC, the estimated SSC from the acoustic technique showed acceptable correlation with lab-based SSC. Therefore, the ADCP-based sediment monitoring could be considered as a practical method for evaluating accurate suspended sediment concentration values.

Additional important advantages of the ADCP profiling method over conventional methods are shorter measurement processing time, lower operating costs, and high spatial and temporal resolution of measurements that enable the investigation of hydro-sedimentological processes in large natural channels, which nowadays are hard to undertake.

Although ADCP show potential for estimating SSC quickly, several issues remain to be explored such as impact of particle size distribution on recorded data and a better understanding of instrument error, especially when it comes to concentration ratios between fine and coarse material using instruments with different acoustic frequency.

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