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Processing of Suspended Sediment Concentration Measurements on Drava River

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Abstract. This paper presents processing of measured concentrations of suspended sediment load in three hydrological stations on the river Drava, Croatia. Measurement data were available for discrete moments during 17-year period (1990-2007) in gauging stations Botovo, Terezino polje, and Donji Miholjac. The data were provided by the National hydrometeorological Institute (DHMZ), which carried out the sampling and initial calculations of concentration. Data processing includes only ¨profile¨ measurements where sediment sampling was done on several verticals and at several depths of the discharge profile. Data processing shows adjustment of the theoretical curve of distribution of concentration of values measured at each station. Mathematical concentrations used in further processing were obtained by excluding outliers in measured data. Further, the paper shows the dependence water surface elevation - discharge, as well as discharge - suspended sediment concentration in the stations, and interdependence of sediment concentrations between the three stations for small, medium and high water flows. Based on the resulting dependence of concentrations between the stations, the estimate is given of concentration of suspended sediment load in the downstream station Belisce. Finally, based on the estimated discharge - sediment concentration dependence on gauging station Donji Miholjac, estimate is given of total annual suspended sediment load for the period 990 – 2007.

Keywords: Suspended sediment concentration, sand-bed river, Drava River

1 Introduction

Suspended sediment load is important for the regime of a watercourse due to its channel-forming property, and its concentration and discharge is monitored in river engineering. Traditionally, measuring of suspended load is done by direct sampling in one or several measuring points in a given designated cross-section. Sediment sampling in a watercourse is a complex procedure due to difficult installing of the measuring equipment and required additional laboratory analysis of collected samples. Duration and extensiveness of works required getting a measuring sample results in measuring discontinuity, and sampling is mainly periodical. As sampling is not automatic and requires human presence, and at certain hydrologic conditions becomes quite impossible, it is often necessary to supplement load measurements with empirically determined relations.

Determining of the relation between discharge and suspended sediment concentration on the basis of measurements makes it possible to extrapolate the results on other hydrological events in the same river reach, and to apply the obtained relations on other river reaches with similar hydrological, hydrodynamic and sedimentological properties.

This paper describes the methodology of processing and analysis of measured hydrological-hydraulic parameters in gauging stations Botovo, Terezino Polje and Donji Miholjac on the Drava River, in a longer period from 1990 to 2007. The measurement data available for the paper included discharge, flow velocity, flow area, free surface top width, mean profile depths and concentrations of suspended load. The paper shows functional relations between the discharge and the concentration of suspended load (*Q*-*C*) and the reliability of the resulting relations. The *Q*-*C* relations for three stations were compared, and the distribution of *Q*-*C* relations along the watercourse was demonstrated. Based on the relations determined in the upstream gauging stations Botovo, Terezino Polje and Donji Miholjac, the estimate was made of the *Q*-*C* relation in the downstream gauging station Belišće. Additionally, the estimate was made of the total annual sediment discharge in the gauging station Donji Miholjac for the period 1990–2007. Statistical analysis of hydrological parameters was made in the program package SAS version 9.1.3.

2 Monitored River Reach

The Drava River springs in Southern Tyrolia and flows through the Austrian province Kärnten, Slovenia, and in Croatia where it forms a part of the Croatian-Hungarian border. Downstream from Donji Miholjac it turns towards inland Croatian territory, towards Osijek and flows into the Danube near Aljmaš on the border between Croatia and Serbia. The total length of Drava River is 749 km, out of which 323 km in the Croatian territory, with the navigation waterway of about 90 km – from the confluence with the Danube to Čađavica. The catchment area of the Drava River is 38.500 km^2 out of which 16,5% on the territory of the Republic of Croatia.

The area involved in the analysis of suspended sediment discharge is situated downstream from the Dubrava Hydroelectric Power Plant (HPP) to the gauging station Belišće (Fig. 1). The paper includes four gauging stations, i.e. Botovo (rkm 226+700), Terezino Polje (rkm 152+700), Donji Miholjac (rkm 77+700), and Belišće (rkm 45+300). The Mura River, with its catchment area of 10.891 km^2 is the largest tributary of Drava, and its mouth is directly downstream of Dubrava HPP (rkm 236+700), and upstream from the gauging station Botovo.

The average annual discharge of the Mura at the mouth is 170 m^3/s, and the average annual discharge of the Drava at the Dubrava HPP is 355 m^3/s. The mean annual discharge measured at the gauging station Belišće, situated downstream from Mura River mouth is 522 m^3/s, which shows that downstream the Mura River mouth there are no major tributaries. The designed discharge of the Dubrava HPP is 500 m^3/s. The water regime of the Drava is pluvial-glacial, characterized by low flows in winter, and high flows in the second half of spring and in summer. However, the natural water and sediment regime has been considerably changed by the dominant influence of a large number of hydropower plants in Austria, Slovenia and Croatia.

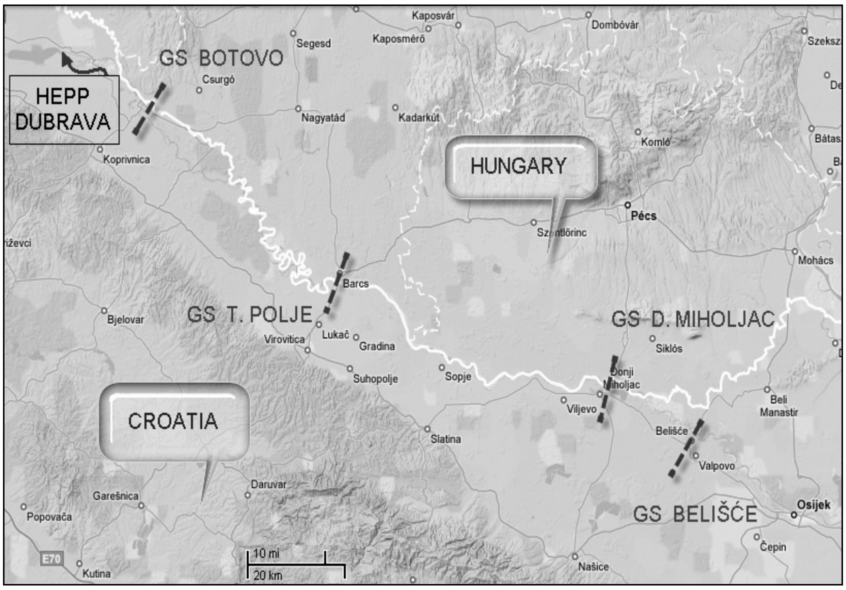

Fig. 1. Geographic location of the Drava River reaches with gauging stations

3 Available Measurements

Measuring of hydrological and hydraulic data, as well as initial processing was provided by the National Hydrometeorological Institute (DHMZ). Through the history of measuring on gauging stations Botovo, Terezino Polje and Donji Miholjac it may be seen that measuring included mean flow velocity, discharge, cross-section geometry, flow area, mean cross-section depth, flow top width at free surface, and suspended sediment discharge. The period involved in this paper is from 1990 to 2007, i.e. the period after construction of the last hydropower plant on Drava River.

Measuring of the suspended load discharge is done on the constant profile in the watercourse, assuming that its geometry will stay unchanged for a longer period (Fig. 2).

In order to determine suspended sediment concentrations, water samples are taken on a daily basis by the measuring vessel at one point on the watercourse surface. The samples are then processed in the National Hydrometeorological Institute by the standard filtration method ISO 4363:2002, giving concentrations of suspended load in g/m^3. On the other hand, profile measurements of discharge and suspended sediment are made in discreet time moments, which make 100 to 150 data sets for each gauging station in 17-year period.

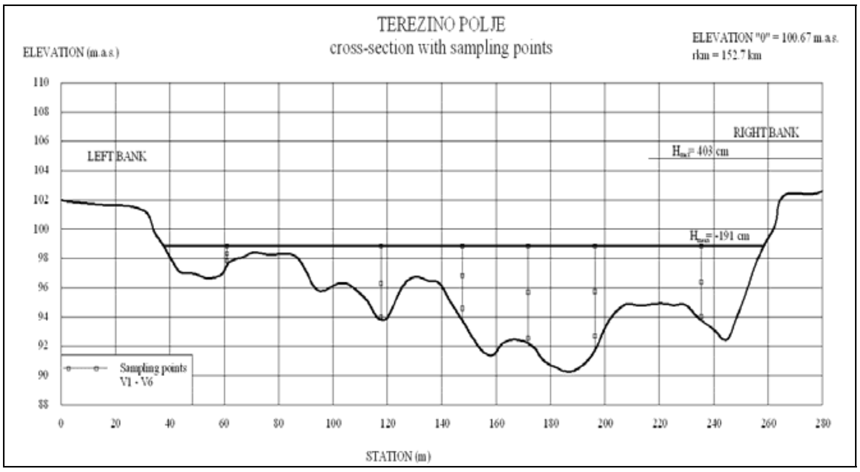

Fig. 2. Channel profile at designated cross section of the gauging station Terezino Polje

In profile measurements samples are taken by a free-flow meter in six cross-section verticals, with three samples per vertical: on the surface, in the middle and at the bottom (Fig. 3). All three samples from a vertical are joined into a single sample and processed ion the laboratory to determine the mean suspended sediment concentration for each vertical.

After processing of separate verticals, the suspended sediment concentration is averaged for the entire cross-section, and the result is referred to as the mean cross-section suspended sediment concentration. In a known designated cross-section the total quantity of suspended sediment load which will be discharged through the cross-section is defined by the double integral:

$$G = \int_0^h \int_0^B v \cdot C \cdot dh \cdot dx \, [\mathrm{kg/s}] \tag{1}$$

This paper analyzes only profile measurements, because hydrological parameters are measured on the entire cross-section of the watercourse, and not only at the surface as in daily measurements. Besides discreet measurements of discharge and suspended sediment, the available data also included water surface level, as continuous records in hourly intervals. Additionally, for the gauging station Belišće, available documentation included the rating curve of the relation between discharges and water surface levels.

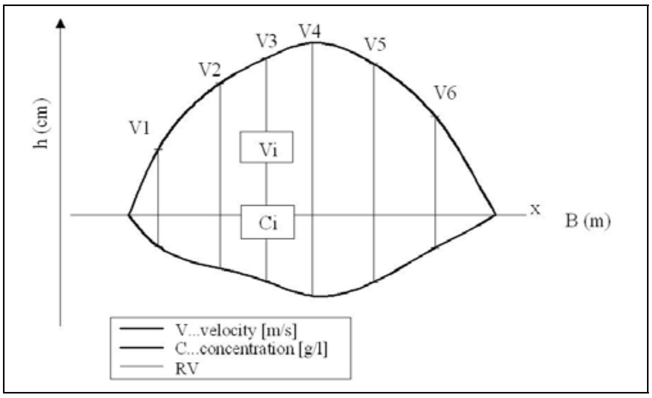

Fig. 3. Schematic of calculation method for cross-section suspended sediment concentration

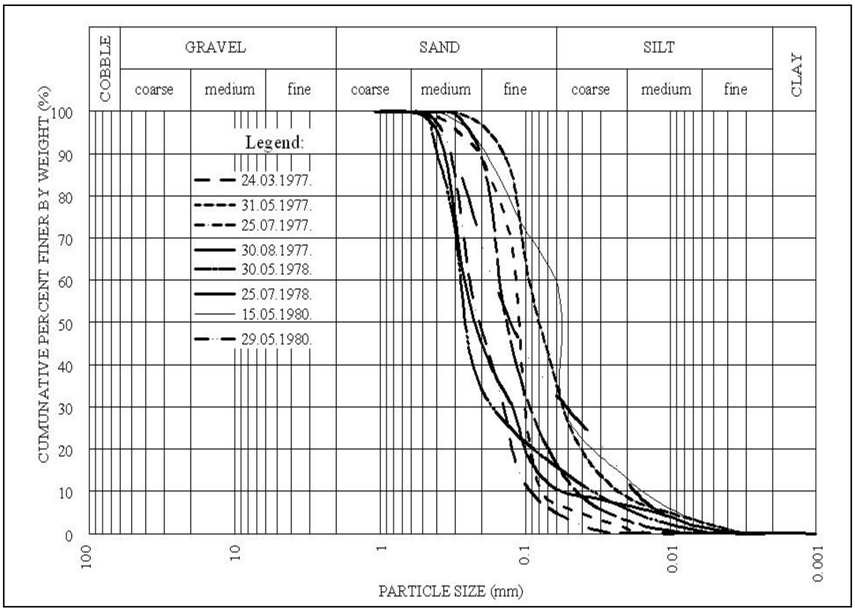

Fig. 4. Grain size distribution curve of suspended load measured on the Drava River

The composition of the suspended sediment was taken over from the study "Forecasts of morphological-psamological processes in the Drava River after construction of the hydropower plant Novo Virje" (IEE, 1997). It may be seen from the grain size distribution curve (Fig. 4) that there are about 70% of sand and about 30% of silt. The mean particle diameter of the suspended load is $d_{50} = 0{,}10$ mm.

4 Quality Control of Measured Values

During the observation period of 17 years, various techniques of measuring of hydrological values were used. Measuring of velocities and determining of discharges was done by means of the hydrological wing on a defined number of points of the hydrological cross-section, and after 2004 data were collected by means of the acoustic flow meter (ADCP). In all measurements on the watercourse, certain outliers among measured values are always expected, regardless of the measuring technique used. Therefore, before the analysis of the relation of discharge and suspended sediment concentration, quality control of measurements was carried out. In previous analyses (Oskoruš, 2008) some functional relations of discharge and suspended sediment concentration for gauging stations on the Drava and the Mura were presented. That work analyzed only the relation between the discharge and the suspended sediment concentration, while for this paper additional hydrological data were available, such as: mean flow velocity, cross-section area, mean cross-section depth and top width of free surface. This allowed more comprehensive control of the quality of measured values.

Outliers in measured values may be the result of measuring errors, but also the values deviating from the global trend and contributing to the characteristics of distribution. Identification of outliers was done with caution, through parallel comparison of the scatter plots of measured values. In the program package SAS, scatter plots were compared for discharge, flow velocity, suspended sediment concentration, mean cross-section depth, water surface level, flow area and free surface top width. All measured values were organized in the matrix, and the interrelation of hydrological values was compared on the interactive interface. All values deviating from the global trend cloud in more than two separate scatter plots was excluded.

Since introduction of ADCP, measuring of discharge, velocity profile and geometry has become considerably simpler and more precise. However, in this modernization measuring of suspended sediment concentration has become a procedure separated from measuring of other parameters. Analysis of covariance in Q-H relation compared the traditional measurements (until 2004) with measurements by ADCP to see if the data may be processed together or should be separated.

In the interrelation of discharge and velocity (Q-v) deviation of some data from the global trend cloud was noticed. The deviations noticed pertain to the group of data after introduction of velocity and discharge measuring by ADCP. Reduction of velocity is noticed at the same discharge in traditional measuring. The analysis of covariance of all measured hydrological values showed that the change of measuring technique influences only flow velocity measurements (Q-v relation), and not other hydrological values, and the conclusion was that the entire set may be considered as a whole.

5 Results

In the program package SAS, the analysis of regression in gauging stations Botovo, Terezino Polje and Donji Miholjac was made for two types of relations, i.e. between the water surface level as the independent variable, and the discharge as the dependent variable, and between the discharge as the independent variable and the water surface level as the dependent variable. To allow proper statistic processing of the sets of data, distribution function of the sets of data which will be dependent variables, i.e. discharge and concentration of suspended load, was analyzed first.

For the analyzed set of data, distribution fitting of theoretical and empiric functions were tested, by the Kolmogorov-Smirnov test. K-S parameter D is the largest absolute difference between the cumulative observed proportion and the cumulative proportion expected on the basis of the hypothesized distribution

The zero hypothesis is tested, that the sample is drawn from a theoretical distribution function, and the threshold of significance of 0.05, i.e. 5 % was chosen. The functions chosen for adjustment are normal, log-normal, Weibull's and exponential. For all selected functions were calculated statistical values of Kolmogorov parameter D and probability p that the sample is drawn from the distribution. They show that the sample is drawn from log-normal distribution, because p-value turned out to be significant only in fitting of log-normal distribution on given dataset.

Table 1. Values of statistical parameters for log-normal distribution fitting

	Station:	D. Miholjac	T. polje	Botovo
Discharge	D:	0.083	0.078	0.092
	p:	0.111	>0.15	>0.15
Suspended sediment concentration	D:	0.059	0.090	0.062
	p:	>0.15	0.112	>0.15

The hypothesis that the linear model of regression does not describe the data better than the model of the mean, i.e. the hypothesis $H_0 : \beta = 0$, at $\alpha = 0.05$, was tested by regression analysis between water level and discharge in all three stations. The alternative hypothesis is $H_a : \beta \neq 0$. It shows that the model is significant, and that the hypothesis H_0 is rejected, and the hypothesis H_a is accepted, i.e. that the constant in linear regression equation is statistically significantly different from 0 and that some relationship exist between dependent and independent variable. The curvature on the residual graph indicates that probably a polynomial of second order or an exponential curve would describe better this set of data, and these analyses were carried out as well. The comparison of regression analyses through the determination coefficient R^2 has shown that in all stations regression through the polynomial of 2nd degree, i.e. square function, describes best the dependence between the water surface level and discharge. The calculated determination coefficients are very high on all stations: Botovo $R^2 = 0.82$, Terezino Polje $R^2 = 0.92$ and Donji Miholjac $R^2 = 0.99$.

Calculated values of stage-discharge curve equations show the following values:
Botovo:

$$Q = 654095 + 44.904 \cdot H^2 - 10837.3 \cdot H \tag{2}$$

Terezino polje:

$$Q = 345438 + 37.7319 \cdot H^2 - 7260.08 \cdot H \tag{3}$$

Donji Miholjac:

$$Q = 190735 + 26.3241 \cdot H^2 - 4480.68 \cdot H \tag{4}$$

As the regressive relation between water surface level and discharge is established, it becomes apparent that it is possible in every moment, with great precision, to calculate the discharge on the basis of the measured water surface level data, and the analysis of regression between the discharge as the independent variable and suspended sediment concentration as the dependent variable can be carried out. Regression analysis in all three stations showed that in all three cases linear regression of logarithm set of data, i.e. exponential function, gives the best description of the dependence between the water surface elevation and the discharge. Calculated determination coefficients in the stations are, as follows: Botovo R^2 = 0.32, Terezino Polje R^2 = 0.34 and Donji Miholjac R^2 = 0.44. The calculated exponential equations of Q-C curves have assumed the following values:
Botovo:

$$C = Q^{1.0408} \cdot e^{-10.3842} \tag{5}$$

Terezino polje:

$$C = Q^{1.1111} \cdot e^{-10.7443} \tag{6}$$

Donji Miholjac:

$$C = Q^{1.1395} \cdot e^{-10.7494} \tag{7}$$

If the regression curves calculated at the logarithmic scale in all stations are compared with a graphic presentation (Fig. 5 and 6), there is a notable growing trend of suspended sediment concentration in the downstream direction for every discharge class. From each Q-C curve, in regular intervals within the limits of Q=200m^3/s to Q=2000m^3/s, the discharge was divided into 24 classes, and the values of suspended sediment concentration were read. Based on the geographic distance between stations along the river course the curve of suspended sediment concentration trend was established, i.e. regression analysis of the trend in the stations was made by exponential curve. The calculated curves were extrapolated 30 km downstream to the gauging station Belišće, where the exponential curve of the relation between discharge and suspended load concentration was calculated with 24 calculated data (Fig. 6). The equation of the Q-C curve in Belišće is:

$$C = Q^{1.1947} \cdot e^{-10.968} \tag{8}$$

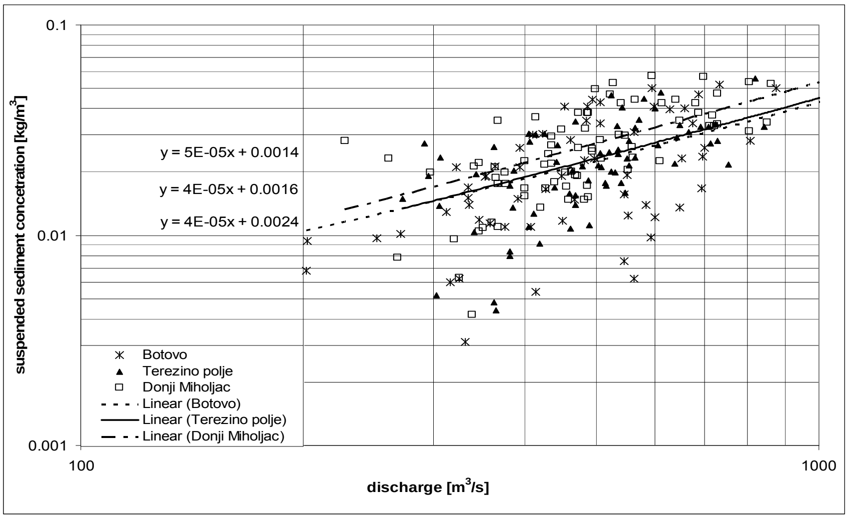

Fig. 5. Presentation of all measured values of suspended load concentration and corresponding discharge with calculated linear regression curves for each station

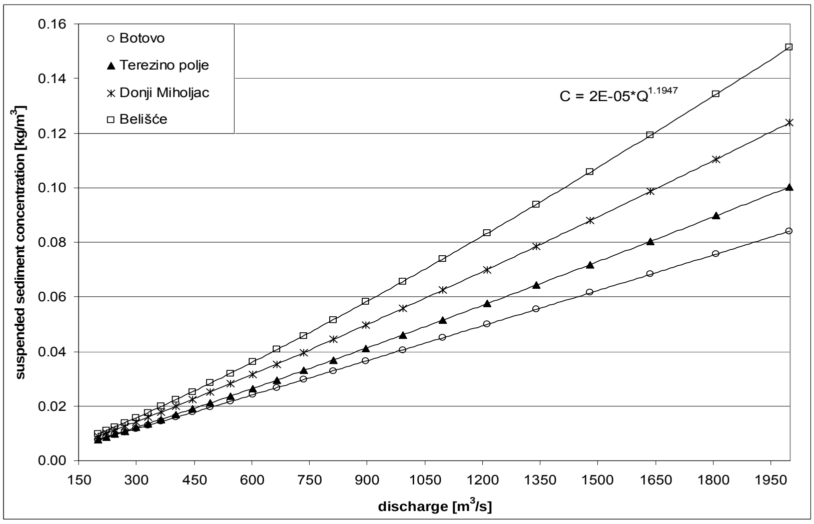

Fig. 6. Relation between *Q*-*C* regression curves in logarithmic scale with the assumed equation on the extrapolated station Belišće

6 Comparison with Previous Analyses

Based on the obtained dependence of the discharge and the suspended sediment concentration, the total annual sediment load *G* was calculated for the period from 1990 to 2007 at the gauging station Donji Miholjac (Fig. 7). Daily data were provided by the National Hydometeorological Institute. Obtained values of total annual sediment load were compared with the values from the paper by Bonacci, D., Oskoruš, D. The influence of three Croatian hydroelectric power plants operation on the Drava River hydrological and sediment regime. The average annual sediment load from cross-section measurements $G_{PROFILE}$ = 483 t/year is higher than the value of average annual yield from point measurement G_{POINT} = 265 t/year, by 87%.

The differences of estimated quantities of sediment are the result of different approach to measuring of sediment concentration.

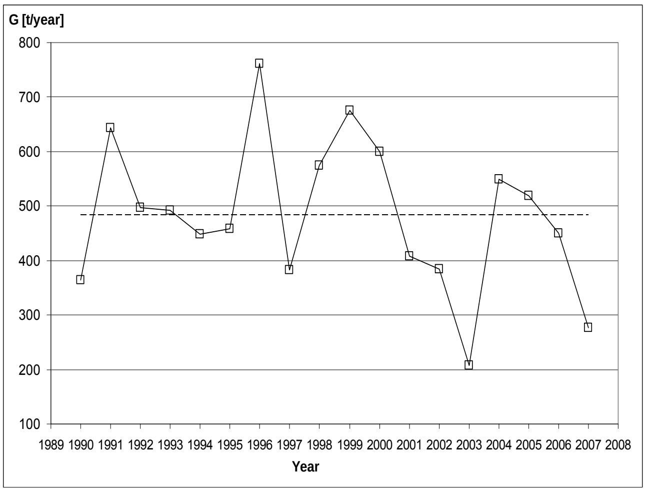

Fig. 7. Measured annual suspended sediment yield at gauging station Donji Miholjac

Previous analyses (Beraković *et al.* 1998) show the *Q-H* curve at the gauging station Botovo, which is compared to the regression relation from this paper. Compared stage-discharge curves are equal at medium and high flows, while discharges at low flows in this paper exceed the discharges from previous analyses.

7 Conclusions

The paper shows the interrelations of hydrological parameters in three gauging stations on the Drava River from Dubrava HPP to Belišće, with particular attention paid to the relation between the discharge and suspended load concentration.

After establishing of uniform relations of water surface level and discharge, and the dependence of discharge and suspended sediment concentration in the stations Botovo, Terezino Polje and Donji Miholjac, the suspended sediment rating curve was estimated on the downstream gauging station Belišće.

Regression relations of hydrological parameters make it possible to estimate suspended sediment concentration on the basis of water surface elevation in four gauging stations on the Drava River. It has been noticed that after construction of the latest hydropower plant (HPP Dubrava) no significant changes of the suspended load regime have occurred, which means that the established relations may be regarded for the entire period after 1990.

Comparison of estimates of the average annual sediment yield made by different sampling methods show that sediment yield from cross-section measurements gives 87% higher suspended sediment concentrations than in point measurements.

The limitation of obtained dependencies of suspended load concentrations is the lack of sediment sampling data in the winter period. As the flow of the Drava River in winter is small, lower reliability of obtained dependencies at low flows is assumed.

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