Sediment transport modelling of the Drava River confluence

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Abstract

Drava River confluence is characterized by specific morphodynamic processes under which significant sediment deposition is occurring at the Drava River confluence, impeding fairway conditions. This paper presents results of detail investigations of morphodynamic changes at the Drava River confluence during the 2-year period. Purpose of the conducted analysis was to estimate morphodynamic development of the riverbed based on the 1D numerical model results. Validation of sediment transport method is done through comparison of morphological changes on characteristic profiles between two consecutive surveys.

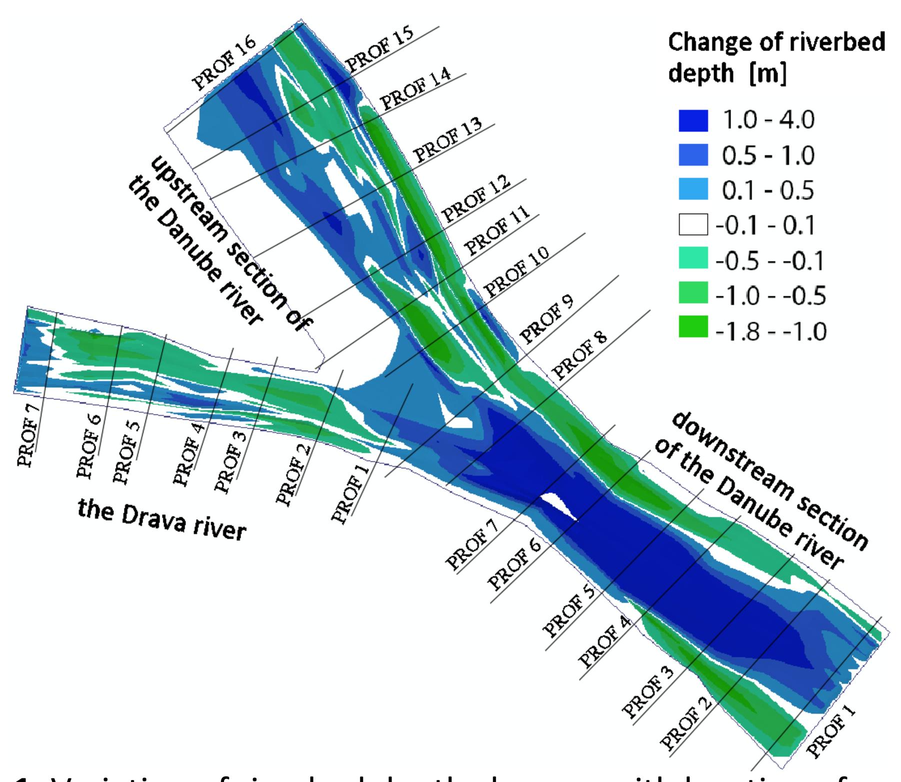

Figure 1. Variation of riverbed depth changes with location of survey profiles

Methodology

Surveys were conducted in July 2016 and October 2018 on 23 profiles at a distance of 125 meters (7 profiles are located on the Drava River, 8 on the upstream and 8 on the downstream section of the Danube). Geodetic-hydrographic surveys of the transverse profiles were performed using a GPS-RTK device that simultaneously locates the position of the boat and the position of the acoustic doppler current profiler (ADCP) that measures the three-dimensional velocity field.

The suspended and bed load sediment samplings were carried out along three transects of the study site (one in the middle of each section). Using a quite high number of concurrent suspended sediment concentration (SSC) from physical isokinetic sampler US-P-61-A and concentration from the acoustic sensor LISST-ABS (~500), a calibration curve has been set up for obtaining a granulometric curve of the suspended sediment. The product of the coherent velocities and concentrations results in a specific sediment discharge (g/sm2) and from the integration of the product along the whole cross-section (t/year), the total sediment load was calculated.

Physical bedload sampler Helley-Smith (8055) intended for sand bed rivers was used for the estimation of the bedload transport. Specific bedload transport rate was calculated as a ratio of the dry sample weight and product of the width of the opening, the sampling time and the density of the sediment. The bedload transport in cross-section is calculated integrating the specific bedload transport along the said cross-section.

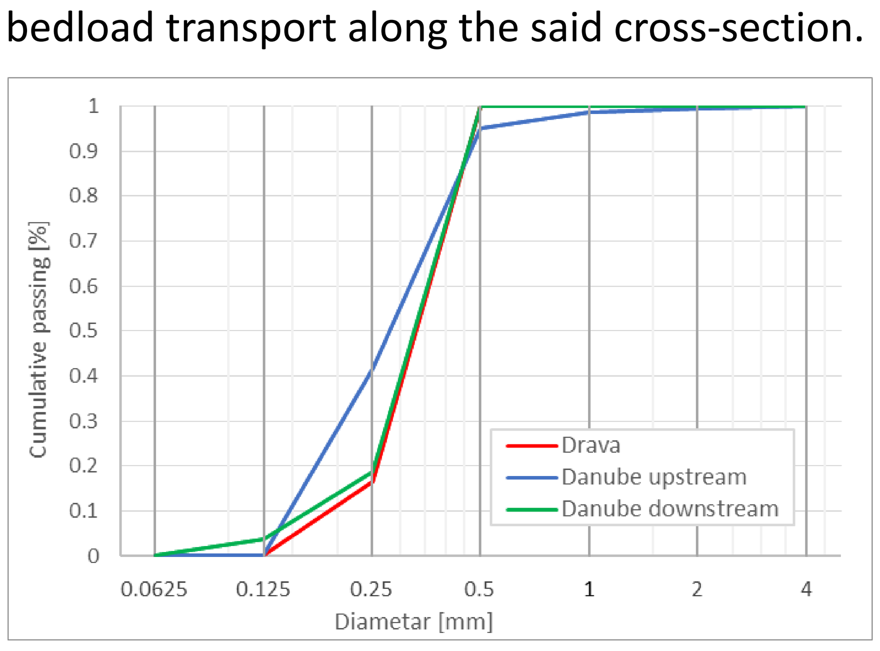

Figure 2. Granulometric bedload composition

One-dimensional numerical model was established in the HEC-RAS 5.0.7 software package. The initial bathymetry of the model corresponds to the first survey conducted in July 2016, with a two-year simulation period. That way, the morphodynamic river bed development could be compared to the survey conducted in October 2018. The mean daily flows, that represent boundary conditions during those two years, were retrieved from the Croatian Meteorological and Hydrological Service. The time step of the quasi-unsteady model was 24 hours long. Granulometric bedload composition was taken from the survey, as well as the SSC-Q curve which represents SSC dependence of the flow rate. Due to the limited number of Q-SSC ratio data, extrapolation with historical data was performed.

Results and discussion

The aim of this paper is to compare the reliability of sediment transport methods at the confluence of the Drava River. For all methods, cumulative mass change on the Drava River gradually decreases in the vicinity of the confluence, which explains deposition. On the Danube River, the amounts of sediment transports are approximately 10x larger than the sediment transport on the Drava River. Approaching the confluence, the Danube deposits sediment on the right bank while erosion is significant along the left bank. Comparing cumulative mass change for different methods, with the same hydrological conditions input, the Meyer Peter Muller method represents the highest amounts of sediment transport, and the lowest values can be observed by the Engelund-Hansen and Yang method.

For all transects, deposition and erosion areas were detected and calculated based on bathymetry of cross-sectional differences at the beginning and at the end of the simulation period. Afterwards, using transect distances total volume of erosion and deposition were obtained along the entire study site for all methods that were calculated in HEC-RAS 5.0.7, as well as for survey data. Data were statistically processed as it is presented in Table 5 that shows the relative deviations of the deposited/eroded volume of each method with respect to the survey database. Results of the Ackers-White and Wilcock Crowe method have the best correspondence with the survey data, and Meyer Peter Muller method deviated the most.

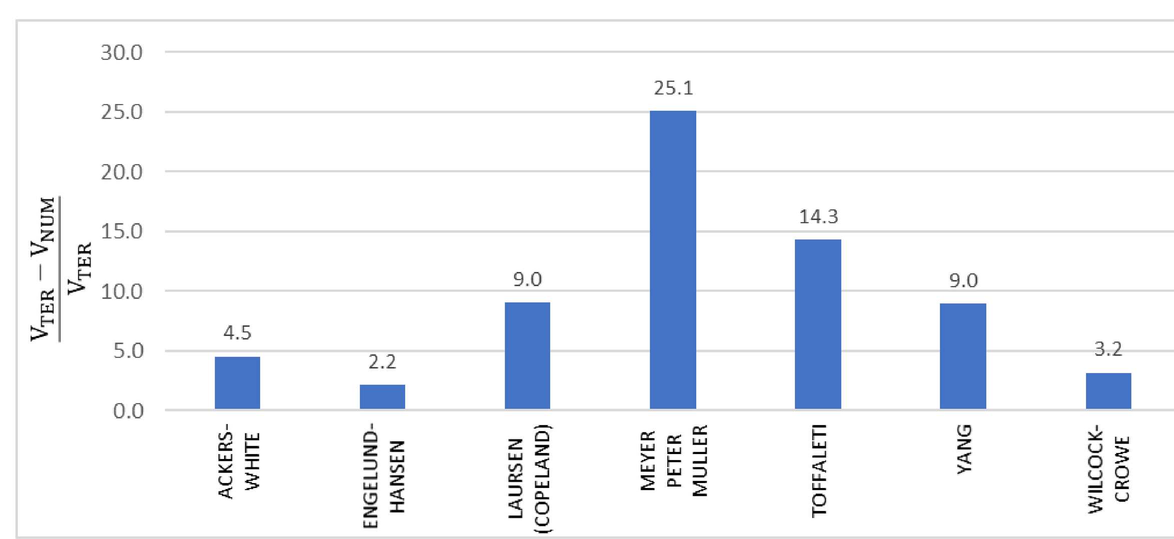

Figure 3. Relative deviation of total volume differences for all methods in comparison to survey database

Meyer-Peter Muller (MPM) bed load transport function is derived for rivers with relatively coarse sediment which explains why it is not applicable for the Drava and the Danube rivers that are uniform sand-bed channels.

Results-wise, Toffaleti follows MPM. It was formulated from regressions on temperature and an empirical exponent that describes the relationship between sediment and hydraulic characteristics. Looking at the input data, the summer water temperature in the study site reaches an average of 22 °C, and the temperature in which the equation was derived was up to 34 °C which could be an indicator of significant deviations. Toffaleti is also sensitive to the fall velocity and for this research the Ruby method was chosen.

Laursen (Copeland) transport function is defined based on depth flow and on the sediment characteristics of gradation, while Yang is based on shear velocity, energy gradient and median particle diameter. For both methods, original conditions that were present for developing of the formula exceed the study sites parameters.

Wilcock-Crowe and Ackers-White methods demonstrate good matches with survey data. Both formulas were developed for relatively uniform gradations ranging from sand to fine gravels. Dominant parameter for Wilcock-Crowe's function is shear stress, and for Ackers-White's function, said parameter is an exponent that depends on particle diameter.

Finally, results of the Engelund-Hansen method correspond best with the survey database. Method is restricted for sand systems with substantial suspended load, just like the Drava and the Danube rivers. Sediment transport is a function of average velocity square, and the range of original velocity field is almost identical to the one in the study site.

Table 1. Range of input values for sediment transport functions

	Overall particle diametar d [mm]	Median particle diametar d_m [mm]	Sediment specific gravity s [g/cm³]	Average channel velocity v [m/s]	Channel depth D [m]	Energy gradient I [m/m]	Channel width B [m]	Hydraulic radius R [m]	Water temperature T [°C]
Ulazni podaci u HEC-RAS	0.004-2		2.65	0.15-1.8	0.2-20.0	0.000006-0.0003	130.0-500.0	0.199-18.52	2.0-22.0
Ackers-White [flume]	0.04-7		1.0-2.7	0.02-2.1	0.003-0.43	0.00006-0.037	0.07-1.2	0.003-0.25	8.0-32.0
Engelund-Hansen [flume]		0.19-0.93		0.2-1.9	0.06-0.4	0.000055-0.019			7.0-34.0
Laursen (Copeland) [field]		0.08 - 0.7		0.02-2.4	0.2-16.5	0.0000021-0.0018	19.2-1109.0	0.196-16.02	0.0 - 34.0
Laursen (Copeland) [field]		0.011-29		0.2-2.9	0.01-1.1	0.00025-0.025	0.07-2.0	0.008-0.52	8.0 - 28.0
Meyer Peter Muller [flume]	0.4-29.0		1.25-4.0	0.4-2.9	0.01-1.2	0.0004-0.02	0.15-2.0	0.009-0.55	
Toffaleti [field]	0.062-4.0	0.095-0.76		0.2-2.4	0.020-17.68	0.000002-0.0011	19.2-1109.0	0.02-17.30	0.0 - 34.0
Toffaleti [flume]	0.062-4.0	0.45-0.91		0.2-1.9	0.024-0.46	0.00014-0.019	0.24-2.4	0.02-0.33	4.0 - 34.0
Yang [field sand]	0.15-1.7			0.2-2.0	0.01-15.2	0.000043-0.028	0.13-533.0	0.009-14.38	0.0 - 34.0
Yang [field gravel]	2.5-7.0			0.4-1.6	0.02-0.22	0.0012-0.029	0.13-533.0	0.015-0.22	0.0 - 34.0
Wilcock-Crowe [flume]	0.5-64	-	-	-	0.09-0.12	-	0.60	0.069-0.086	-

Conclusion

After sensitivity analysis of methods for calculating sediment transport it can be concluded that the Engelund-Hansen method is the most applicable at the mouth of the Drava River to the Danube river. The method that deviates the most from survey is the Meyer-Peter & Muller method. Due to specific hydraulic conditions at the mouth of the Drava River: high rate of turbulence and mixing sediment using solely one method for sediment transport calculation is not recommended. Therefore, beside Engelund-Hansen method, Ackers-White and Wilcock-Crowe method should also be taken into consideration.