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PhD thesis book

Three-dimensional analysis of river hydrodynamics and morphology

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Preliminaries and research tools

One of the oldest research field of hydraulic engineering sciences is the investigation of flow and sediment transport processes in rivers. Field measurements play an important role in hydro- and morphodynamical research of rivers and due to the dynamic development of measurement tools, in the last decade, field data with increasingly higher space and time resolution can be evaluated. In the development of flow measurement techniques acoustic Doppler profilers (ADCP) meant a significant step. Using of such tool mounted on a boat, spatial distribution of flow velocities can be measured with explicitly set time resolution and a space resolution according to boat speed. Velocity measurements with higher boat speed offer a general, but locally instantaneous, spatial velocity field of the study reach, whereas slow or even standing measurement results in a time series of velocity from a given profile. Advantage of the former case consists in having a spatially large scale information, while the latter method can provide detailed temporal data. Using time averaged vertical velocity profiles from fixed-boat measurements the well known analytical logarithmic profile of turbulent boundary layer flows can be fitted on measured values. From the parameters of the logarithmic function, roughness height or bed shear stress can be estimated, in addition, a characteristic longitudinal dispersion coefficient can also be evaluated playing an important role in mixing processes. One part of this thesis consists in field measurements and their analysis, as mentioned above.

The second investigation tool applied in this work is the three-dimensional numerical modeling of flows and sediment transport. On today's development level of hardware and software increasingly complex river engineering tasks can be managed, and thus, three-dimensional morphological modeling of river reaches became a potential tool. Whereas in most numerical modeling studies one and two-dimensional description of flows may be sufficient, in some special cases three-dimensional closure is needed. For instance, flow structures in river bends or in the vicinity of hydraulic structures are evidently three-dimensional, and this spatial character directly affects sediment or pollutant transport processes. It can be stated, moreover, that 3D Computational Fluid Dynamics (CFD) codes estimate more accurately flow conditions close to river bed, which can be especially important in case of modeling bed changes, since sediment erosion and deposition processes take place here.

Field measurements can be efficiently used for studying river flows and with appropriate analysis of the data, the method can be a suitable investigation tool in itself. Contrarily, following general practice CFD models can be a reliable tool only once they have been calibrated and validated against measured data. However, recently more and more CFD applications can be used in place of field or laboratory experiments in situations, where flow conditions are hardly measurable or can not be measured at all.

Objectives

Performing up-to-date field surveys together with three-dimensional numerical flow and sediment modeling, the main objectives of this thesis are the followings:

- To prove that time averaged vertical velocity profiles produced by long-term fixed point ADCP measurements are suitable to reveal spatial flow features in confluence flows.
- To show that the numerical tool chosen in this research can reproduce the unique flow structures in river confluences.
- To introduce a method and prove its suitability for the derivation of hydromorphological features from velocity profiling, focusing on the bed roughness height, bed shear velocity and longitudinal dispersion coefficient.
- To validate a three-dimensional numerical flow model and couple it with suitable empirical sediment load formulae for quantitative estimation of bed level changes in a large sand bed and gravel-sand bed river.
- To show that the chosen numerical morphodynamical model is capable to estimate the impacts of new river regulation activities on river morphology.
- To introduce and calibrate a method for the estimation of suspended solids concentration in rivers from ADCP backscatter signal.
- To quantify the error in sediment discharge estimation caused by ADCP measurement uncertainties and data filtering.

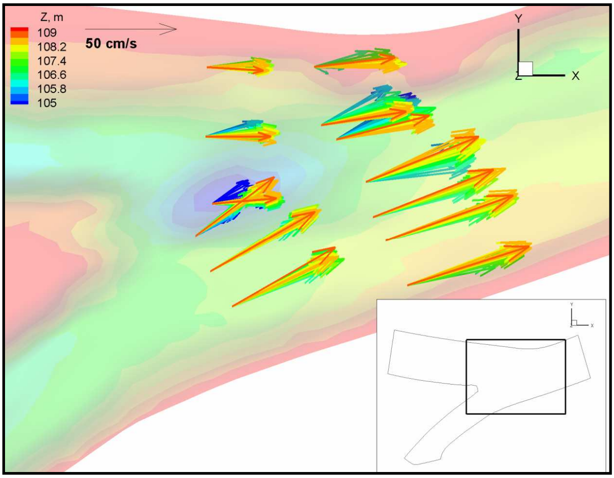
New scientific results

As a summary of this work the main new results and conclusions are reported in the form of theses.

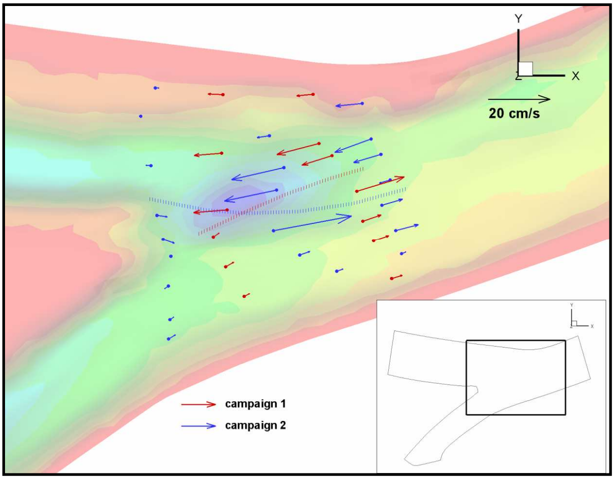
Thesis 1 *Three-dimensional flow structure in river confluence*

I proved that long-term fixed point velocity profiling is essential, at the same time sufficient to reveal the spatial flow features in confluence zones. Based on the measured velocity vector field I derived a vectorial representation of the secondary current component of the flow resulting in the circulation per unit width, providing both the strength and orientation of the helical motion. Successful three-dimensional model adaptation reproduced these flow structures and confirmed the dependence of such structures on the ratio of the momentum carried by the two rivers joining each other. [1]

Detailed investigations at the junction of two moderate size rivers (River Mosoni-Duna and River Rába) clearly showed the development and complexity of the significant helical behavior in the confluence flow. Such a behavior can be largely explained by the plan form of the merging rivers. Since the investigated rivers reach the confluence zone in bends of opposite sense, they are already in swirling motion, which is further enhanced when joining each other. Apart from fixed point profiling, cross-sectional moving boat ADCP measurements supported three-dimensional numerical flow model validation.



Plan view of time averaged velocity vectors from fixed boat ADCP measurements.

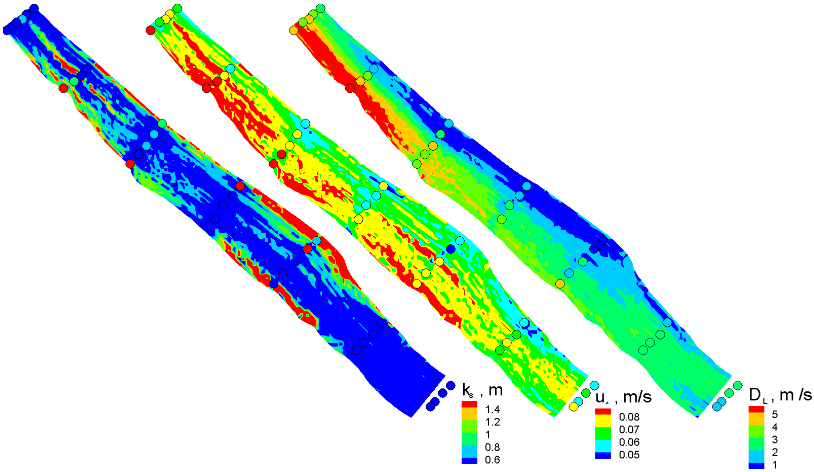


Plan view of circulation vectors from the two measurement campaigns.

Thesis 2 *Velocity profiling-based derivation of hydro-morphological features*

I proved that both fixed point and moving boat velocity profiling are suitable for estimating bed roughness height, bed shear velocity and longitudinal dispersion coefficient in large rivers. Fitting of logarithmic analytical functions to time-averaged vertical profiles in fixed points as well as to space-time averaged profiles from moving boat survey provide reasonable roughness height and shear velocity values. Roughness height values largely exceeding the ones expected from skin friction indicate the presence of dunes, often developing in sand bed river reaches. Besides the qualitative observation of such bed forms, even their quantification can be carried out by the proposed method, confirmed also by known empirical formulae. An order of magnitude estimate of the streamwise turbulent dispersion coefficient could be obtained by numerically evaluating Elder's triple integral formula. [3]

The analysis of numerous measurements in River Danube showed that time-averaged velocity profiles obtained from sufficiently long term fixed boat ADCP measurements fitted well with analytical velocity profiles, characteristic to turbulent boundary layer flows. The least square based fitting procedure provided the bed roughness height and shear velocity, as two parameters of the analytical profile. In moving boat velocity profiling individual vertical velocity distributions showed significant scattering due to turbulence. Nevertheless, applying local space and time averaging resulted in reasonably smooth, but still realistic distribution on which analytical profiles with high correlation could be fitted. All this provided then either cross-sectional or aerial distribution of the above mentioned parameters.



Parameter distributions derived from ADCP data (left: Nikuradze roughness; mid: Bed shear velocity; right: Longitudinal dispersion coefficient).

Thesis 3 *Modeling morphodynamics of large sand-bed rivers*

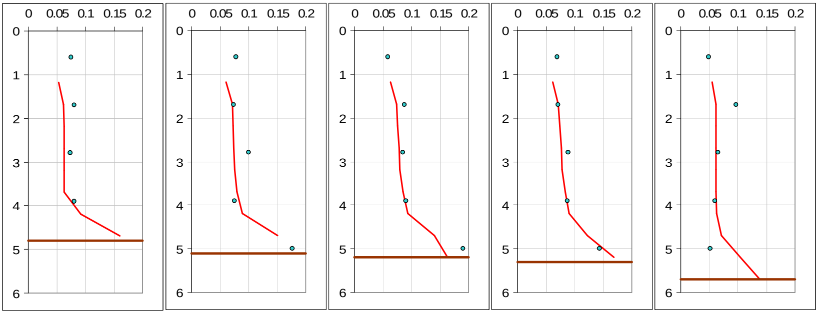
In the morphodynamical investigation of the Hungarian lower Danube, as typical large sandy bed river, I proved the necessity of multi-fractional approach of sediment transport modeling. As a good compromise the application of three fractions handled with van Rijn's corresponding total load formula provided reasonable fitting of measured and modeled bed changes. Successful parameterization required detailed *in situ* flow measurement, sediment sampling as well as morphological surveying. A baseline measurement of these parameters in low flow regime, compared to measurements after bed forming moderate floods, provided valuable information on the dynamic behavior of the investigated river reach. An unsteady 3D morphological model validated on such a measurement period is suitable then to simulate bed changes provoked by new river training works, though in the latter bed equilibrium is disturbed by changes applied in the geometry rather than in the flow regime. [4]

I note that a large part of the Hungarian Danube is characterized by gravel-sand bed, where the proper quantitative description of bed changes is in general more complicated than in the case of purely sandy grain composition. The gravel fraction enhances the importance of bed-load transport, along with the hiding of the small grain fractions due to the sheltering effect of the large ones. Despite this complexity, applying Wu's formula developed for such conditions supplied with careful, field measurement-based parameterization could reasonably reproduce the significant stability of the bed geometry and grain composition in such Danube reach, shown also by field measurements.

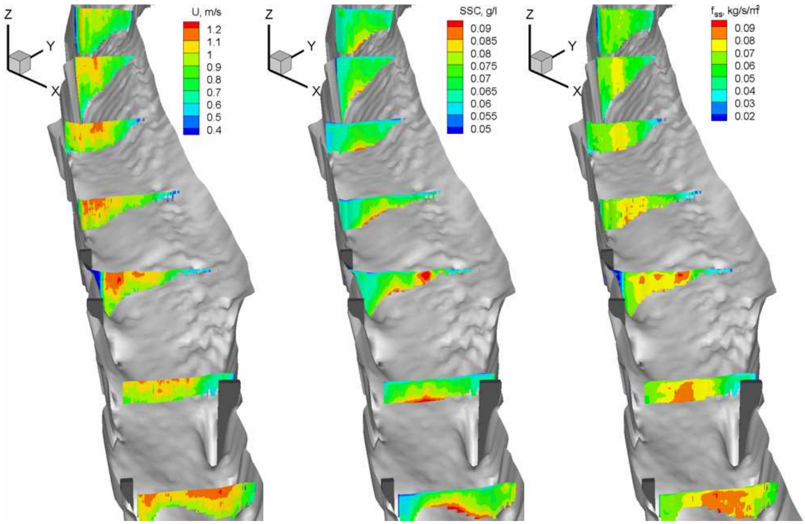
Thesis 4 *Estimation of suspended solids concentration from ADCP backscatter data*

I implemented a novel estimation procedure for suspended solids concentration based on the intensity of backscattered sound of acoustic Doppler current profilers. Based on detailed moving and fixed boat ADCP measurements together with sediment sampling I successfully calibrated the estimation method for a Danube reach characterized by significant suspended solids transport. The effect of measurement uncertainty and data filtering on sediment flux determination was also analyzed and quantified. [2]

Some of the parameters playing a role in the description of sound propagation in water were estimated based on known empirical formulas, whereas the others could be measured. Regression analysis was applied to obtain a relationship between backscattered sound intensity and sediment concentration. The formula established in such a way was then used to estimate sediment concentrations from ADCP data along verticals in fixed boat measurements and along moving boat path-lines. I showed that measurement uncertainty inherent in acoustic Doppler and enhanced by the complexity of the near-bottom sediment-laden flow has significant effect both on local sediment flux estimation. In turn, smoothing of raw velocity and backscatter intensity data showed insignificant impact on cross-sectional sediment discharge estimation.



Measured (dots) and estimated (lines) sediment concentration profiles (Horizontal-axis: SSC, g/l; Vertical-axis: depth, m).



Spatial distribution of measured flow velocities (left), derived sediment concentrations (mid) and calculated sediment fluxes (right).

List of publications related to the thesis

1. **Baranya S.**, Józsa J. (2007): Numerical and laboratory investigation of the hydrodynamic complexity of a river confluence. ***PERIOD POLYTECH CIV ENG*** **51:**(1) *3-8.*

2. **Baranya S**., Józsa J. (2010): ADCP alkalmazása lebegtetett hordalék koncentráció becslésére. ***HIDROLÓGIAI KÖZLÖNY*** szerk. alatt. 7 o.

3. **Baranya S.**, Józsa J. (2009): ADCP data analysis to explore hydro-morphologic and dispersion conditions in the Hungarian Danube. In: Proc. *7th ISE & 8th HIC*, Concepción, Chile. , 2009.01.16-2009.01.19. 10 p. Paper conf187a323.

4. **Baranya S.**, Józsa J. (2009): Morphological modelling of a sand-bed reach in the Hungarian Danube. In: *Proc. XXXIII. IAHR Congress*. Vancouver, Kanada, 2009.08.09-14. pp. 3680-3687.