Modeling river bed morphology with special reference to the bottlenecks in the Green Danube Corridor

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Introduction – Progress in developing a new integrated planning process

Previous issues of "Danube News" addressed the problem that ongoing or planned projects in the Danube River may affect its hydromorphology and, hence, the ecological conditions in the river and its landscape (e.g. Bloesch 2007). Schabuss & Schiemer (2007) deal with possible threats through navigation and point to the bottleneck sections of the Danube where river engineering measures should ensure navigation in times of low water levels. These bottlenecks, however, are also highly valued "hotspots of diversity" (Kutzenberger & Nichersu 2007). Schabuss and Schiemer further argue that the "latest innovations both in navigation infrastructure and river engineering as well as in life sciences must be considered and applied" to find ecologically acceptable solutions.

An essential step forward in developing a planning process that considers such arguments can be seen in the "Joint Statement on Guiding Principles for the Development of Inland Navigation and Environmental Protection in the Danube River Basin" prepared by ICPDR. This document introduces a new integrated planning philosophy and advocates for developing a joint approach that is designed to meet both the needs of Inland Waterway Transport (IWT) and ecological integrity. It further contains recommendations for planning principles and criteria for river engineering to obtain sustainable development. In the context of river morphology, the following two principles should be considered: the principle of "working with nature" and the principle to implement measures in an adaptive form. This implies that measures should be implemented – wherever possible – "according to given natural river-morphological processes ...".

Studies on river morphology including comprehensive in situ observations and measurements must be performed to provide the basis for the planning process. For example, monitoring and modeling are an essential part of the "Integrated River Engineering Project on the Danube to the East of Vienna (IREP) to get a sound understanding of the morphological processes (Habersack et al. 2008).

Understanding morphological processes in the river – a prerequisite for the planning process

Morphological dynamics is the result of a complex interplay of sediment input to, and local sediment transport in, a river reach and varies considerably at different temporal and spatial scales. Rivers develop characteristic features of planform, channel pattern, gradient, type of bed material etc. depending on how this interplay works under the specific geomorphologic and hydrologic conditions. This allows to classify river courses as straight, braided, meandering, anastomosed, etc., which helps to assess the principal processes determining the changes and variations of the morphological structures of a river section.

Applied to the Danube, the natural river landscapes with floodplains of the Upper Danube are braided and anabranched river sections (Hohensinner et al. 2008). Both river planform and floodplain connections were, however, heavily altered mostly by channelization. Now these river sections exhibit straight or slightly sinuous channels with alternate bars.

Quite different is the picture of the Lower Danube. The river with its varying widths, its tendency to build multiple branches and islands, with its much lower gradient and much finer bed material, can be classified as an anastomosed river. The wide channel sections are prone to frequent in-channel bar and island formation by sand and silt deposition. Permanent variations in extent, location, and height of these bed forms contribute to an ecologically highly valued variety of flow and water depth. However, they also cause frequent changes in location and depths of the navigation fairway. Sections with "over-width" (very wide channel sections) are also prone to permanent bank erosion which can amount to several meters per year (Phare 2000).

Many processes at different scales contribute to the occurrence and development of various bed and riverine structures and variations in sediment transport. To characterize a river reach in detail, cross-section profiles, bed forms (type, location, length, and height), longitudinal profile and gradient are to be studied by considering information on sediments (bed load and suspended load, grain sizes and gradation). From recurrent bathymetric surveys river bed changes in space and time, and the dynamics of bed forms, bars, scours and fords can be deduced. *Figure 1* shows the result of such an analysis and the consequences of the big flood in August 2002 for an 8 km long section of the Austrian Danube. The two upper maps (02-1 and 02-2) show various bar sections (brown-yellow bar and deep-blue scour cross-section parts) and ford sections between the bars. From the third map (meas) the areas of deposition or erosion can be identified.

Further, detailed studies of river engineering (groynes etc.) at five fords in the Austrian Danube east of Vienna were performed by DonauConsult (2004). Ideally, an analysis of the current state of the river is completed by historical data. Such information is now available, e.g., for two river-flood-

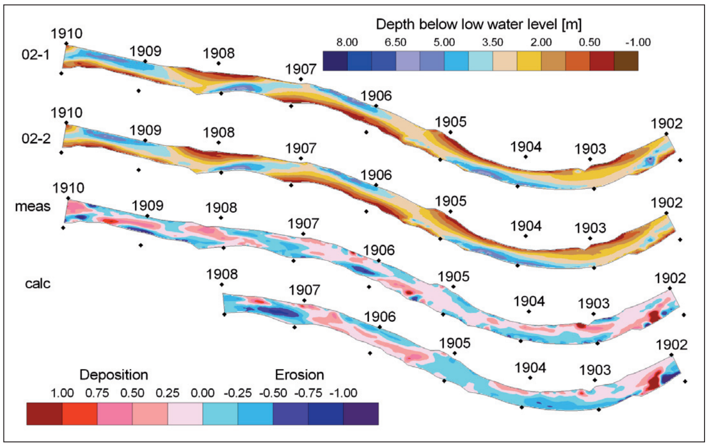

Figure 1. Morphological changes of an 8 km long reach of the Austrian Danube east of Vienna during the flood episode 2002: water depths (below the reference low water level) according bathymetric surveys before (02-1) and after (02-2) the flood; bars and fords are characterized by brown-yellow colour, deep-blue colour shows the pools; observed (meas) and calculated (calc) river bed changes (areas of deposition or erosion) between the two surveys (Fischer-Antze 2005)

plain systems of the Austrian Danube (Hohensinner et al. 2008). Data reconstructed from historical maps of the river landscapes – in this case maps of 1812 for the Machland area and 1849 for the Lobau area – were used to quantify characteristic features such as the water-covered areas and the bank lengths of the "Active Zones". Comparison with corresponding results for the current situation highlights the tremendous changes in hydrological surface connectivity due to the channelization in the 19th and 20th century and helps to identify the basis of sustainable and effective river restoration concepts.

Modev (2005) described the characteristics of six selected bottlenecks in the Bulgarian part of the Green Danube Corridor (Somovit, Malka Barzina, Milka, Batin, Mishka, Popina), based on bathymetric and hydraulic data and water levels. The morphological features – location and development of bars, islands and banks – provided a classification in five groups that may help to assess river engineering measures in accordance with the morphological regime in these river sections.

Comparing old river maps was also a starting point to gain insight into the morphological changes over time at a reference section of the Lower Danube (Behr et al. 2000). To make the surveys performed in the two countries Bulgaria and Romania comparable, a special procedure based on local coordinate transformations was developed to transfer the maps based on different coordinate and height systems to produce the gridded difference maps (Phare 2000). The results showed a strong movement of river bed in the given time.

All these studies showed that such analyses of river bed morphology are necessary to understand the occurrence, formation and alteration of the morphological features of a river and are, therefore, also a prerequisite to modeling.

Modeling river bed morphology – examples from the Danube River Basin

Models are usually classified as 1D-, 2D-, and 3D-models depending on the number of dimensions incorporated in the model. Viewed from the aspect of enabling to capture the 3-dimensional features of a river bed, 3D-models would be ideally suited for morphological studies. There are, however, some obstacles against a wide spread use of such models as their application is associated with long computational times and the need of detailed observational data for calibration. Current state-of-the-art is the application of 2D-models. Allowing to describe the flow processes in the longitudinal and in the transversal dimension, they can be applied to model channel-floodplain interactions and flow and transport variations in channels with non-uniform shape. 1D-models have been so far the backbone of many studies which were designed to simulate sediment balances in long river-reaches and over longer time scales.

Before 2000, mainly empirical approaches based on channel parameter, cross-section-flow relationships, and sediment balance estimates were applied in the Danube River due to the fact that river bed surveys were not available (Phare 2000). An exception are a few applications of 1D- and 2D-hydrodynamic models to study suspended sediment transport, river bed changes, and modifications of the Danube upstream of Nagymaros (Hungary), in a Serbian river section (rkm 1333-1317), and in the backwater zones of Iron Gate I dam. Other studies using hydrodynamic models were devoted to describe flow patterns, velocity and shear stress distributions as a basis to conclude on river engineering measures.

The progress in model development and computer techniques has led to a new level of hydrodynamic models. In the Bavarian Danube the flow and morphological evolution in the Straubing-Vilshofen reach was investigated by several authors. Well documented is the application of the 2D-model FAST2D to study the morphological changes under extreme hydraulic conditions in typical flood situations in the river section between rkm 2282 and rkm 2265 (Minh Duc et al. 2005). In the Austrian Danube Fischer-Antze (2005) employed the 3D SSIIM-model (Olsen 2002) to simulate river bed changes during the flood episode of August 2002 *(Figure 1)*. The lowermost map ("calc" in *Figure 1)* shows the calculated bed changes (in m erosion or deposition, respectively) in comparison to the observed ones ("meas"). Reasonable accuracy in representing the relevant morphological features has been achieved.

Related to the ongoing studies in the frame of the IREP-project mentioned above a new 3D-model (Rsim-3D, Tritthart 2005) has been designed to model the interactions between the channel and the groyne fields in the 40 km long Danube River section downstream of Vienna (Tritthart et al. 2009). The model is part of the strong efforts to provide the means for the continuous monitoring and modeling activities planned to accompany and assess the various engineering and ecological measures employed in the course of the project (Habersack et al. 2008).

Another study on the Hungarian Danube deals with the application of the 3D SSIIM-model to simulate the flow and sediment transport processes in a 6 km long river section with several groynes downstream of Mohács where a sequence of an over-widened and a shallow channel section causes frequent navigational difficulties (Rákóczi et al. 2008).

Outlook and conclusions

The examples given above may point towards the future direction of modeling river bed morphology to support an integrated planning process. The models used in these studies allowed to capture flow and transport phenomena such as secondary currents, non-uniform sediment transport, and sorting and armouring processes. They were applied to study dune and bar movements, the exchange processes between the river channel and groyne fields, and the impact of structures on river morphology, features that may be of paramount importance when the morphological situation of the bottleneck sections of the Lower Danube shall be analysed and modeled.

References

Behr O, Gutknecht D, Modev S, Bondar C, Prohaska S (2000): Danube river morphology: a common initiative was taken. Danube Watch 1/2000, 6–8

Bloesch J (2007): Editorial Danube News 15, 1

DonauConsult Zottl & Erber (2004): Flussbauliches Gesamtprojekt östlich von Wien. Variantenvergleich: Furtendynamik – Zusammenfassende Darstellung. Erstellt im Auftrag von Wasserstraßendirektion. Juni 2004

Fischer-Antze T (2005): Assessing river bed changes by morphological and numerical analysis. Ph.D. Thesis, Vienna Univ. Technology, 179 pp

Habersack H, Hauer C, Liedermann M, Tritthart M (2008): Modelling and monitoring aid management of the Austrian Danube. Water21, Dec. 2008, 29–31

Hohensinner S, Herrnegger M, Blaschke A P, Habereder C, Haidvogl G, Hein T, Jungwirth M, Weiß M (2008): Type-specific reference conditions of fluvial landscapes: A search in the past by 3D-reconstruction. Catena 75, 200–215

Kutzenberger H, Nichersu I (2007): Towards an integrated planning approach in the Danubs River Basin. Danube News 16, 2-4

Minh Duc B, Bernhart HH, Kleemeier H (2005): Morphological numerical simulation of flood situations in the Danube River. Int J River Basin Management 3 No.4, 283–293

Modev S (2005): Bottlenecks in the Lower Danube River. In: Bloesch J, Gutknecht D, Iordache V (eds), Hydrology and Limnology – Another Boundary in the Danube River Basin, IHP-VI Technical Documents in Hydrology No. 75, 65–74

Olsen NRB (2002): A three-dimensional numerical model for simulation of sediment movements in water intakes with moving option. User`s Manual, Department of Hydraulic and Environmental Engineering, The Norwegian University of Science and Technology, Trondheim, Norway

Phare (2000): Morphological changes and abatement of their negative effects on a selected part of the Danube river. Phare Project OSS 98-5303.00. Final report, September 2000

Rákóczi L, Baranya S, Jósza J (2008): Improving the navigability on a sand-bed section of the Hungarian Danube reach. In: Altinakar, Kokpinar, Gogus, Tayfur, Kumcu, Yildirim (eds), River Flow 2008, 1497–1503

Schabuss M, Schiemer F (2007): Key threats to the Danube in the IAD perspective. No.1, Navigation: Is there a potential for compromising the contradictory stakeholder interests? Danube News 15, 2–4

Tritthart M (2005): Three-dimensional numerical modelling of turbulent river flow using polyhedral finite volumes. Wiener Mitteilungen Wasser-Abwasser-Gewässer 193, 1-179, www.tuwien.ac.at/publications/downloads

Tritthart M, Liedermann M, Habersack H (2009): Modelling spatio-temporal flow characteristics in groyne fields. River. Res. Applic. 25, 62–81

An integrated model approach for sustainable floodplain management: the case study of the urban floodplain Lobau

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Introduction

Floodplains are highly endangered ecosystems as shown for the Danube River Basin, where about 80% of the pristine floodplain areas are lost (WWF 1999). The remaining areas show a distinct decline of ecosystem functions and services. In face of the increasing ecological and socio-economic constraints on river floodplain systems, sustainable management strategies are urgently needed. However, conflicts among the various societal demands and utilizations tighten the potential for good solutions. An additional challenge is the often limited understanding of these complex systems, especially as regards the interaction between different natural and anthropogenic driving forces. With respect to a sustainable development of the ecosystem, management approaches must be based on predictive geomorphological, hydrological and ecological models as well as on the comparison with reference conditions or guiding images which give an insight into the complex interactions of the different compartments. Especially in urban areas, ecological objectives have to integrate the many-fold, often conflicting social and economic demands and involve local and regional stakeholders in a participatory process to raise public support for the proposed strategies (Hargrove et al. 2005).

From a methodological point of view, the integration of the various ecological and socio-economic aspects of urban floodplain management often confronts managers and scientists with the problem of the incomparability of quantitative and qualitative data. Together with contradicting objectives