Sediment research and management – Transnational tasks along the Danube River

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Abstract

Sediment transport is an essential element of any river system. It affects a variety of sectors that are directly or indirectly related to the river. These include hydropower utilization, inland navigation, agriculture, flood protection, water supply and also the habitats that the river provides for animals and plants. Several ongoing and recently completed international projects collect data and perform numerical as well as physical modelling to improve the knowledge of the sediment transport in the Danube River. These data are an important basis to identify the driving forces behind changes in sediment regime and to investigate and develop measures for a more sustainable sediment management.

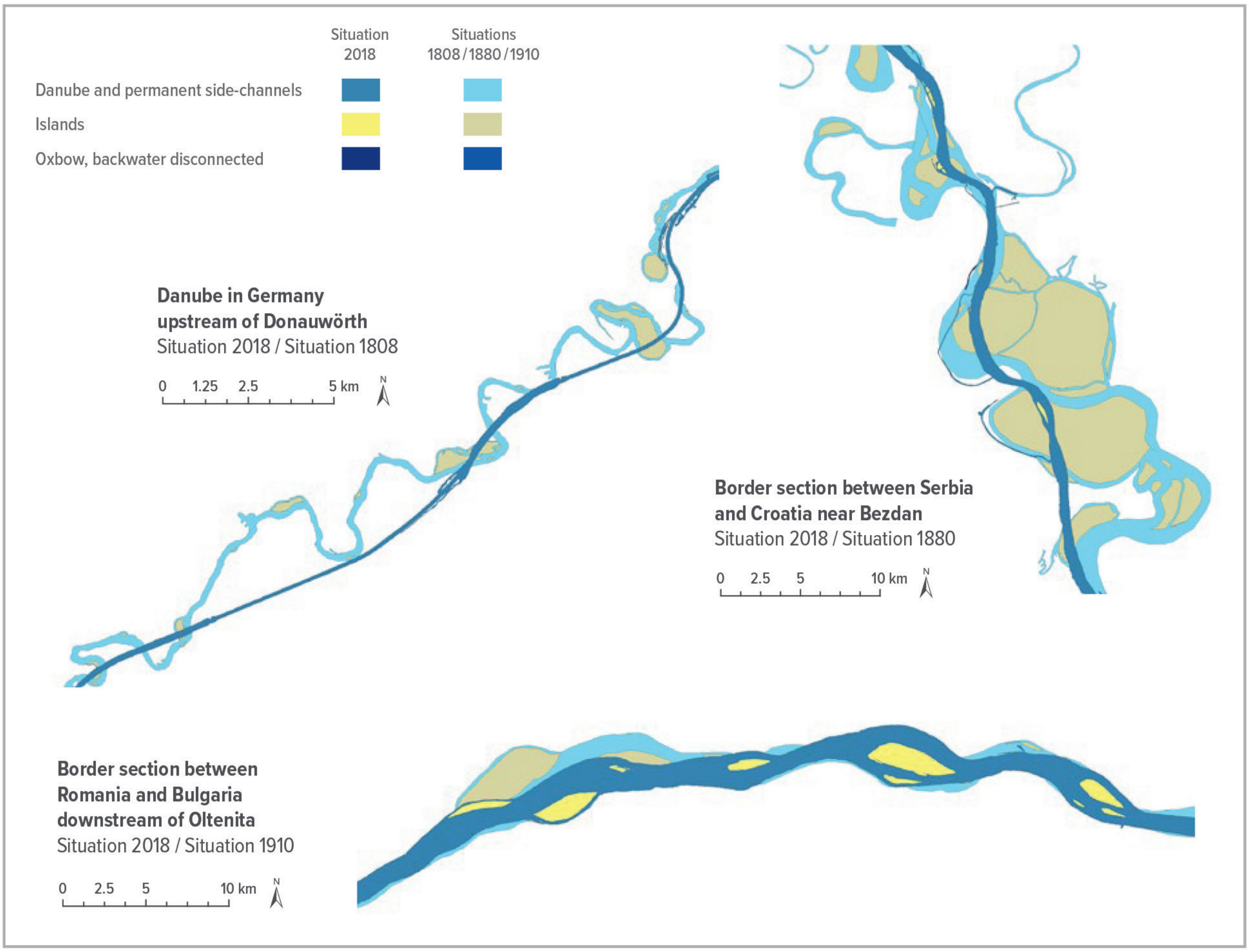

Figure 1. Top left: Danube in Germany upstream of Donauwörth. Top right: Border section between Serbia and Croatia near Bezdan. Bottom: Border section between Romania and Bulgaria downstream of Oltenita (based on data collected for the DanubeSediment Report 'Long-term Morphological Development of the Danube in Relation to the Sediment Balance'). (Habersack et al. 2019a).

Human intervention

Since the 18th century, humans have intervened considerably in the river system of the Danube. For inland navigation and flood protection, but also for land reclamation for settlements and agriculture, the course and banks of the river were changed by straightening and narrowing. Bank protection measures and cut-off side channels as well as flood protection dykes hinder the lateral exchange of sediments. At several sections of the river, significant dredging activities took place in the past, to gain construction material. More recently, the Danube River and many of its tributaries were dammed by transverse structures to generate energy from hydropower.

This has significantly altered the dynamic processes of sediment transport and morphodynamics typical for the rivers. When sediment input to and transport in rivers is reduced or absent, this might lead to severe erosion of the riverbed. This, in turn, results in a drop in the water level and instability of structures on and in the river. In impounded areas, as found upstream of transverse structures, sediments were deposited, which can endanger flood protection or can cause problems with hydropower utilization. But sediment management is also necessary from a nature conservation perspective, because the deterioration of the sediment balance, such as the retention of sediments at dams, leads to the loss of spawning habitats in the river and to a drop in the groundwater level in the floodplains, among other things.

Already a decade ago, the International Commission for the Protection of the Danube River (ICPDR) addressed the changes in the sediment regime of the Danube River as a problem in the first Danube River Basin Management Plan (DRBMP) of 2009 describing the sediment budget of most major rivers of the Danube basin as disturbed or severely altered (ICPDR 2009). However, the exact effects of these alterations were unknown. For this reason, the overall picture of the Danube's sediment regime was to be investigated in the transnational project DanubeSediment (co-funded by the European Union funds ERDF and IPA in the frame of the Danube Transnational Programme).

Morphological changes

Investigations performed in the project DanubeSediment showed to what significant extent the morphology of the Danube River was changed. In the Upper and Middle Danube, larger sections have changed from the former complex river morphology with meandering and sinuous river types with several multi-thread anabranching reaches to a single thread sinuous river type *(fig. 1)*. Especially in these two sections,

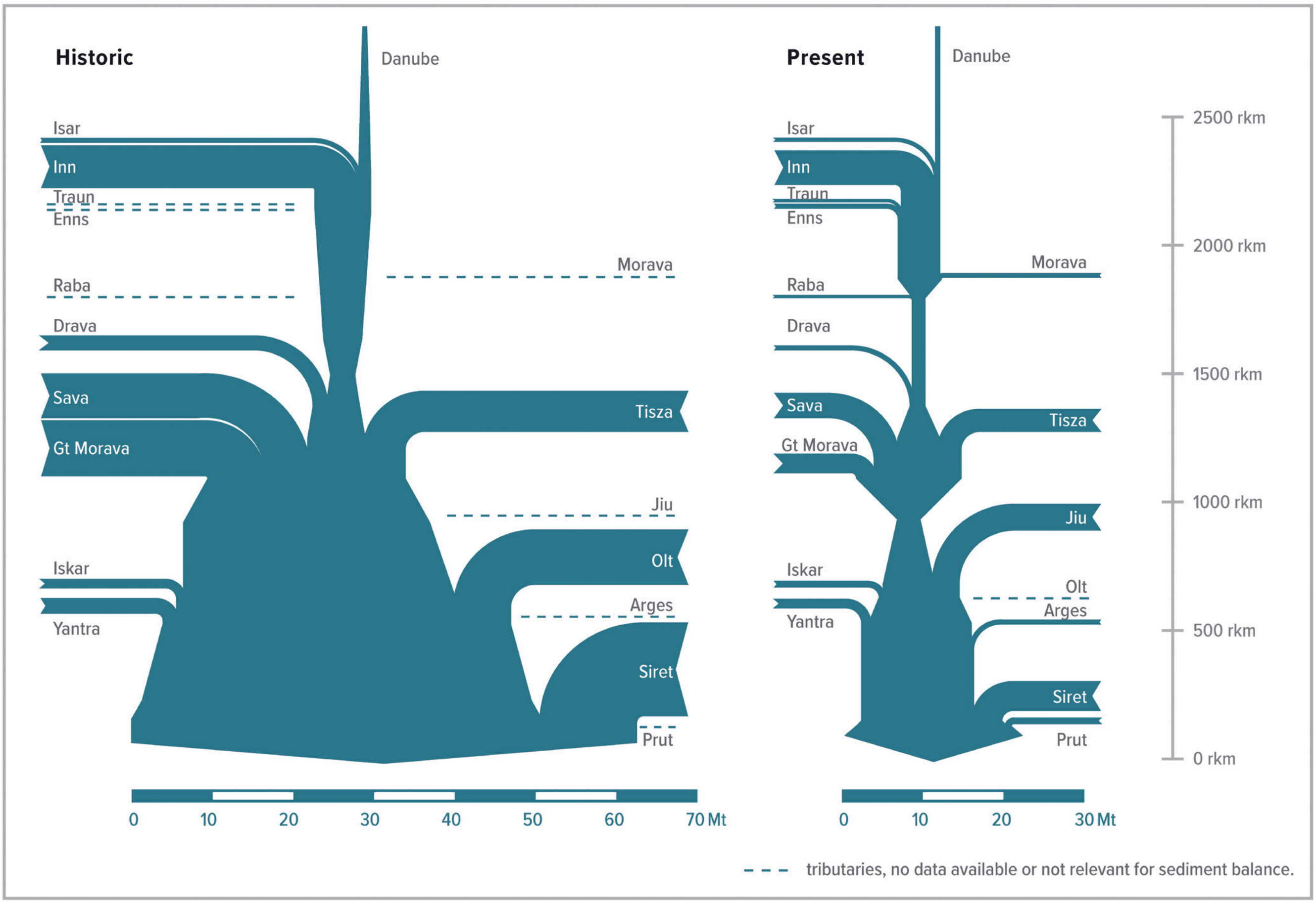

Figure 2. Suspended sediment balance along the Danube River and its major tributaries before (left) and after (right) HPP construction on the Danube River (dashed lines: tributaries, where no data are available or which are no longer relevant for the suspended sediment balance). The horizontal scale (Mt) applies for both the Danube River and its tributaries (based on data from the DanubeSediment report 'Analysis of Sediment Data Collected along the Danube') (Habersack et al. 2019a,b).

the width of the Danube River and its floodplains as well as the river length were significantly reduced. The total length of the Danube was shortened by 134 river-km, thereof 98 river-km (11%) on the Upper Danube and 31 river-km (4%) on the Middle Danube. In the Upper Danube, the total width was decreased on average by 39% (the active width by 22%) and in the Middle Danube by 12% (the active width by 1%) (Habersack et al. 2019 a,b). The construction of artificial structures such as guiding walls and groynes further reduced the width at low water level. As a consequence of these changes, various forms of riverbed degradation occurred and naturally-formed sediment bars, islands, side channels and oxbow lakes have been substantially reduced in the remaining free-flowing sections. The results of this project show that the lateral restrictions due to river training are less severe in the case of the Lower Danube River. Thus, the length decreased only about 1%, and the mean total width changed by 4%, whereby the width of the active river increased by 1% (Habersack et al. 2019a,b).

First sediment balance at the Danube River

The first step in establishing the sediment balance of the Danube River was to collect and analyse a large amount of sediment transport data. The majority of the sediment monitoring stations (more than 60) collect data on suspended sediments, while only eight stations with data on bedload are available. Since bedload has a large effect on river morphology compared to suspended sediment, its monitoring is of considerable importance for the sediment balance.

After harmonising the different data sets, a suspended sediment balance of the Danube River could be set up for two different time periods also considering the most important tributaries at their most downstream monitoring stations *(fig. 2).* Since the construction of the large hydropower plants on the Danube River and its tributaries, the annual suspended sediment load reaching the Danube Delta and the Black Sea has decreased by up to 60%. Historically, about 60 and 40 million tonnes reached the Danube Delta and Black Sea annually, whereas today only about 20 and 15 million tonnes of suspended sediments arrive (Habersack et al. 2019a,b). The interruption of river continuity also prevents the bedload transport, resulting in a lack of river-forming sediments.

In order to compile the first sediment balance of the Danube River, further data such as dredging and feeding amounts of sediments and the composition and grain size of the transported sediments and bed material were collected. Furthermore, longitudinal and transverse profiles were used to investigate changes in bed levels for different time periods.

Overall, the assumption was confirmed that sediment tends to be deposited in impounded areas, while erosion mainly occurs in the free-flowing sections. An overview for the entire Danube River is shown in *Figure 3*. Around 733 river-km of the Danube are characterised by erosion. In the Lower Danube, the data are insufficient for long

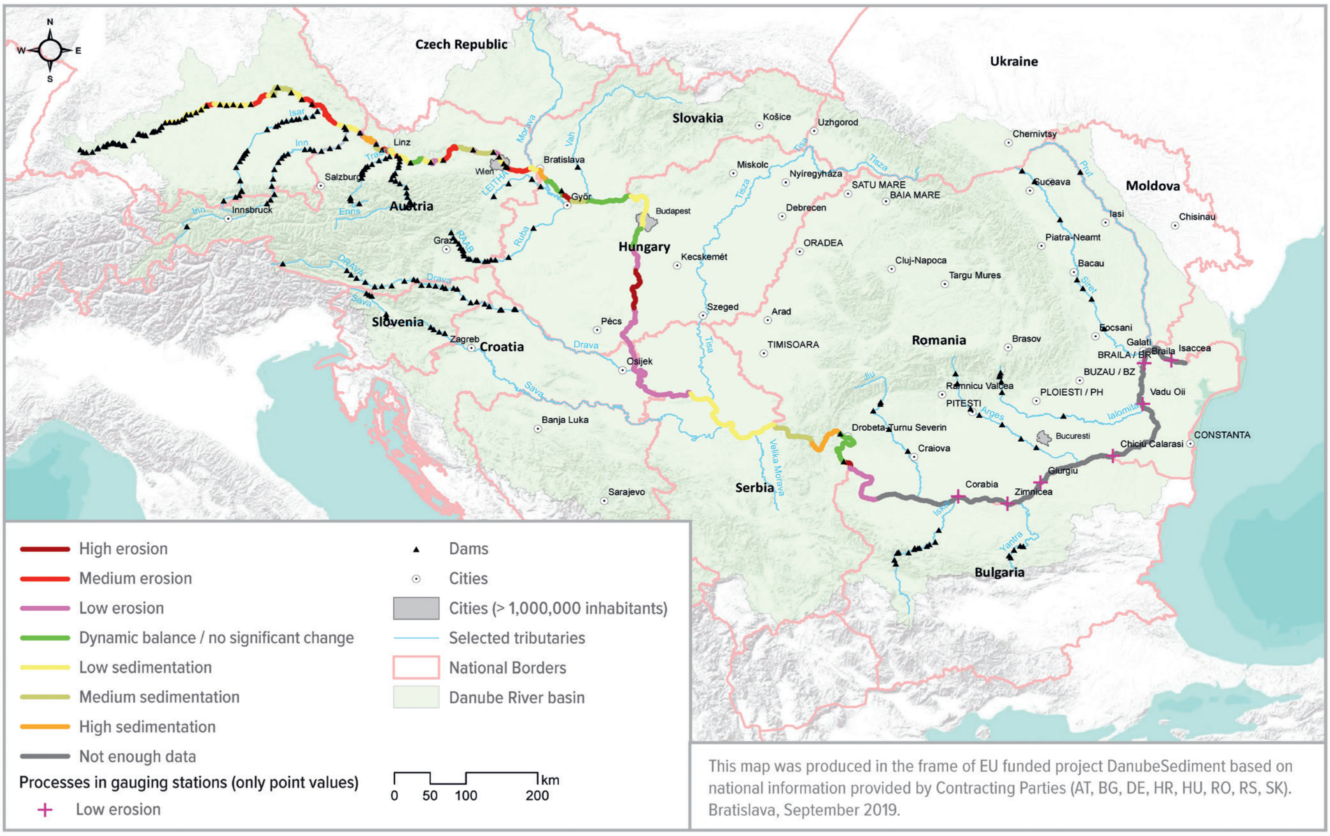

Figure 3. Reaches at the Upper, Middle and Lower Danube showing sedimentation and erosion (from the DanubeSediment report 'Long-term Morphological Development of the Danube in Relation to the Sediment Balance') (Habersack et al. 2019a,b).

stretches, but point data at gauging stations indicate an erosion trend for about 670 river-km downstream of Iron Gate II. Altogether, about 56% of the entire Danube River is subject to an erosional tendency. In contrast, sedimentation prevails on about 857 river-km, especially upstream of the power plants Aschach, Gabčíkovo and Iron Gate I. Along 241 river-km or 10% of the Danube River, a more or less dynamic equilibrium can be observed or no significant changes occur (Habersack et al. 2019 a,b).

Significant Water Management Issue

The project results highlight that the sediment regime at the Danube River is out of balance. As a consequence of the project results, the ICPDR Heads of Delegations identified the sediment balance alteration as a new sub-item under the existing Significant Water Management Issue “Hydromorphological alterations” in the 2021 Update of the Danube River Basin Management Plan (ICPDR 2021a).

Furthermore, the project provides recommendations, summarized in the Danube Sediment Management Guidance (Habersack et al. 2019a), to reduce the impacts of the disturbed sediment balance. Project results and recommendations were integrated to the Danube River Management Plan and the Danube Flood Risk Management Plan published by the ICPDR and thus the project directly contributed to transnational water management and flood risk prevention (ICPDR 2021a,b).

Bilateral cooperation

Nevertheless, the project results of DanubeSediment also highlighted deficits and needs for actions, for example in data acquisition and needs for harmonization of monitoring and modelling tools, especially in border regions. Two transnational projects, that address these sediment issues in bilateral cooperation between Austria and Slovakia as well as Austria and Hungary, are ‘Danube River Research and Management in Slovakia and Austria, DREAM SK-AT’ (Interreg V-A SK-AT) and ‘Sediment Research and Management on the Danube II, SEDDON II’ (Interreg V-A HU-AT). Research in SEDDON II is carried out in the stretch east of Vienna, focusing on a 10 km long stretch near Hainburg, and in the upper section of the Hungarian Danube, whereas DREAM SK-AT concentrates on the common border section of the Danube River. In these two projects, sediment monitoring stations are set up in Slovakia and Hungary to measure the suspended sediment transport continuously based on the methodology already used in Austria. Furthermore, joint measurements are carried out to compare monitoring devices and to harmonize the monitoring method for suspended sediments and bedload *(fig. 4).*

The collected monitoring data also serve as input data and for calibration and validation of models on sediment transport and morphodynamics. With the help of numerical

Figure 4. Comparison of different monitoring devices to determine suspended sediments during a joint measurement: US-P61-A1 suspended sediment sampler, Acoustic Doppler Velocimeter (ADV) and turbidity sensor

simulations *(fig. 5a)* and physical model tests *(fig. 6),* basic investigations are carried out to better understand sediment-related processes. As sediment is difficult to scale, the set-up of large-scale experiments are required and thus a special focus is given on scaling effects – from small flumes to 1:1 experiments – to improve process understanding. Innovative Methods of modern measurement instruments (LDA = Laser Doppler Anemometry, PIV = Particle Image Velocimetry) are also investigated on different scales. Furthermore, results for modern river engineering and sediment management measures are provided. The spectrum ranges from measures to reduce bed incision for the improvement of the ecological status and optimisations in connection with reservoirs. In the border reach *(fig. 5b)* effects of sedimentation and ecological impacts in sidearms in the headwater of the reservoir (Gabčíkovo) are investigated with the help of numerical models.

Furthermore, in Slovakia and Hungary, lab facilities are renovated and improved and in Vienna a new hydraulic engineering laboratory with a discharge up to 10 m³/s is constructed. This leads to a fundamental improvement of the research infrastructure and cooperation between research institutions in the Danube Region. This new hydraulic engineering laboratory, in combination with the existing laboratories, offer a unique opportunity for the application of physical models on a large scale, from basic to applied research. Especially the large-scale model tests are very important in sediment transport research, as many currently used formulas show limitations in practice and scale effects can then be observed. Moreover, this innovative research site enables new possibilities also for joint research and international cooperation.

Stakeholder Involvement

In addition to enhanced scientific exchange, the improvement of knowledge and the knowledge transfer from science to river management is considered particularly important in all these projects. Thus, stakeholder workshops are organized, where the project results are presented

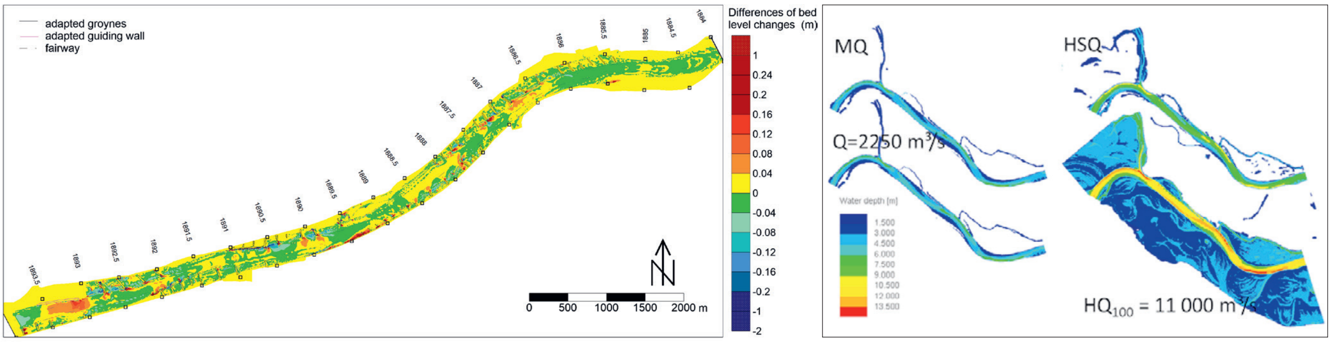

Figure 5. Examples of numerical simulations including (a) sediment transport and morphodynamic model results in the reach near Hainburg (SEDDON II) and (b) 3D hydrodynamic models in the border reach for sediment and ecologically related issues (DREAM SK-AT).

Figure 6. Physical model experiments at different scales.

and discussed together with participants from universities, waterway and water management authorities, environmental organisations (e.g. national parks), hydropower companies and companies working in the field of water management.

Furthermore, the project DanubeSediment specifically targeted the key stakeholders and their roles in its second major output: The Sediment Manual for Stakeholders (SMS) (Habersack et al. 2019b). The SMS provides guidance for sediment-related actions in the Danube River Basin and for future programs of sediment-related measures. The document also provides background information of good practice implementation in each field which can assist decision-makers and practitioners in planning future sediment management measures.

Further information

The Construction of the new hydraulic engineering laboratory of BOKU in Vienna is co-financed by EU funds (Interreg V-A SK-AT, Interreg V-A HU-AT, Interreg V-A AT-CZ, IGJ/ERDF); Austrian Federal Ministry of Agriculture, Regions and Tourism; Austrian Federal Ministry of Education, Science and Research; City of Vienna and Federal Government of Lower Austria).

Further information on the projects can be found under:
DanubeSediment: https://www.interreg-danube.eu/approved-projects/danubesediment
DREAM SK-AT: https://dream-sk-at.jimdosite.com/
SEDDON II: http://www.interreg-athu.eu/seddon2

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Interreg Danube Transnational Programme DanubeSediment — European Union

Interreg Austria–Hungary — European Union – European Regional Development Fund — SEDDON II

Interreg Slovakia-Austria — European Regional Development Fund — European Union