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Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective

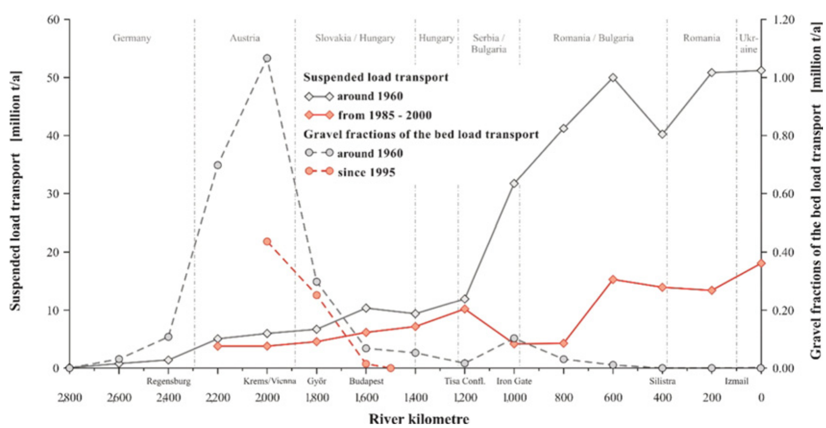
Helmut Habersack [a,*], Thomas Hein [b,c], Adrian Stanica [d], Igor Liska [e], Raimund Mair [e], Elisabeth Jäger [a], Christoph Hauer [a], Chris Bradley [f]

[a] *University of Natural Resources and Life Sciences, Institute of Water Management, Hydrology and Hydraulic Engineering, Christian Doppler Laboratory for Advanced Methods in River Monitoring, Modelling and Engineering, Muthgasse 107, 1190 Vienna, Austria*
[b] *WasserCluster Lunz GmbH, Lunz am See, Austria*
[c] *University of Natural Resources and Life Sciences, Institute of Hydrobiology and Aquatic Ecosystem Management, Vienna, Austria*
[d] *National Institute of Marine Geology and Geo-ecology, GeoEcoMar, Bucharest, Romania*
[e] *International Commission for the Protection of the Danube River, ICPDR, Vienna, Austria*
[f] *School of Geography, Earth and Environmental Sciences, the University of Birmingham, Birmingham, UK*

HIGHLIGHTS

- Hydropower, navigation, and flood protection resulted in a widely engineered Danube River
- River engineering affects significantly hydrodynamics and river morphodynamics (hydromorphology) of the Danube River.
- Sediment surplus exists in impoundments and lack of sediments in free flowing sections.
- River bed erosion causes technical and ecological deficits.
- An improved river basin management needs an advanced knowledge exchange and transfer between environmental researchers, key stakeholders and managers.

GRAPHICAL ABSTRACT



(a) Suspended load transport within the Danube River, (b) gravel fractions of the bed load transport within the Danube River.

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ABSTRACT

In the Danube River Basin multiple pressures affect the river system as a consequence of river engineering works, altering both the river hydrodynamics and morphodynamics. The main objective of this paper is to identify the effects of hydropower development, flood protection and engineering works for navigation on the Danube and to examine specific impacts of these developments on sediment transport and river morphology. Whereas impoundments are characterised by deposition and an excess of sediment with remobilisation of fine sediments during severe floods, the remaining five free flowing sections of the Danube are experiencing river bed erosion of the order of several centimetres per year. Besides the effect of interruption of the sediment continuum, river bed degradation is caused by an increase in the sediment transport capacity following an increase in slope, a reduction of river bed width due to canalisation, prohibition of bank erosion by riprap or regressive erosion following base level lowering by flood protection measures and sediment dredging. As a consequence, the groundwater table is lowered, side-arms are disconnected, instream structures are lost and habitat quality deteriorates

* Corresponding author.
E-mail address: helmut.habersack@boku.ac.at (H. Habersack).

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affecting the ecological status of valuable floodplains. The lack of sediments, together with cutting off meanders, leads also to erosion of the bed of main arms in the Danube Delta and coastal erosion. This paper details the causes and effects of river engineering measures and hydromorphological changes for the Danube. It highlights the importance of adopting a basin-wide holistic approach to river management and demonstrates that past management in the basin has been characterised by a lack of integration. To-date insufficient attention has been paid to the wide-ranging impacts of river engineering works throughout the basin: from the basin headwaters to the Danube Delta, on the Black Sea coast. This highlights the importance of new initiatives that seek to advance knowledge exchange and knowledge transfer within the basin to reach the goal of integrated basin management.

1. Introduction

Globally rivers and their basins have been progressively impacted by human activity, as part of the wider modification of the global hydrological cycle through the Anthropocene (Vörösmarty et al., 2013). In many cases these impacts have been cumulative; associated with marked changes in river flow (Poff and Matthews, 2013), sediment (Syvitski et al., 2009), and nutrient flux (Seitzinger et al., 2006), and changes in the relationship between rivers and their basins. The latter include the loss of lateral connectivity (i.e. between river and floodplain, which negatively influences the exchange processes between various highly dynamic floodplains and the main channel; Wiens, 2002; Allan, 2004), longitudinal continuity (from the basin headwaters downstream) as well as the vertical connectivity (between channel and contiguous groundwater; Ward, 1989). A combination of land use change and river and floodplain engineering works over past decades adds time as the fourth dimension (temporal scale; Ward, 1989). These changes have wider implications for basin hydrology, fluvial geomorphology and the conservation and management of freshwater biodiversity to the extent that it is now difficult to identify 'pristine' or 'reference' rivers against which the effects of anthropogenic change can be measured (Buise et al., 2003). Moreover, there are increasing problems in reconciling the conflicting demands placed upon river basins: in ensuring water security, providing flood protection, and enabling the development of hydropower whilst conserving associated ecosystem services, and minimizing the loss of biodiversity. Whilst these tensions are widely recognised (Vörösmarty et al., 2010) frequently the approaches to river and basin management have been reductionist in nature, given the need for river managers to adopt a pragmatic approach to advance the goal of sustainable river basin management (Newson and Large, 2006; Arthington et al., 2010).

The scale of the problems that arise in managing river basins is exemplified by the practical difficulties associated with maintaining, or improving, river hydromorphology. The latter is the product of the interaction between geomorphology and hydrology as they vary spatially and temporally through the basin (Vaughan et al., 2009; Habersack et al., 2013; Gurnell et al., 2015). As such hydromorphology integrates channel geomorphology with the flow regime and characterises the relationship between variations in river depth and width, and river morphology, at different levels: from river bed structure and substrate at individual reach scales, to the wider structure and form of the riparian zone as it varies through the basin. A major challenge, however, lies in identifying those processes that are responsible for changes in river hydrodynamics, as well as the morphodynamics, of a river, given possible confounding effects, such as pollution (Vaughan et al., 2009), changes in river regime, and in patterns of water abstraction and use through the basin.

The problems are compounded by the extent to which these challenges are scale-dependent. Brierley et al. (2013) note the importance of placing the short-term (and local) problem of relating process-to-form at a particle, bedform and reach scale, in a wider context of the long-term complexities and uncertainties of basin-scale behaviour. This emphasis on landscape connectivity reinforces earlier work on the need to view streams within their basin context (Frissell et al., 1986), characterised by downstream changes in the predominance of individual process domains (Montgomery, 1999). Yet whilst natural or pristine rivers may self-regulate, being free to aggrade or degrade vertically, and/or to move laterally, most rivers are laterally confined to varying degrees, their flows regulated by impoundments and abstraction. This has implications for the degree to which managed rivers are able to continue to self-regulate and adjust to changing boundary conditions whilst also providing essential ecosystem services in the context of cumulative (and progressive) changes in their basins (Hauer et al., 2014; Gurnell et al., 2015; Blamauer et al., 2015). Such concerns are particularly important in 'large river basins' which can exhibit complex and dynamic interactions and occasional non-linear behaviour with varying resilience to external pressures, and are often characterised by high levels of uncertainty.

Within this wider context, a number of approaches have sought to advance the goal of integrated basin management by reconciling differing perspectives of river management (Hering et al., 2010). In Europe, the European Water Framework Directive 2000/60/EC (WFD) has been developed to form a new legal basis for water management. It offers a legal framework to protect and restore water bodies across Europe. It advocates water management within drainage basins, setting Member States specific deadlines to protect aquatic ecosystems and assuring the good ecological and chemical status of water bodies. The WFD specifically emphasises the importance of maintaining, or improving, the hydromorphology of a river, given its ecological significance and the degree to which the hydromorphology depends upon river process dynamics at different scales. However, this priority must be balanced against the importance of ensuring continued protection from flooding (covered by the Floods Directive 2007/60/EC); maintaining, or developing, navigation potential and allowing the sustainable development of hydropower. Clearly there are a number of contradictions here: notably in protecting the water environment whilst ensuring appropriate basin water use. These are acknowledged by the WFD, in advocating a focus on the drainage basin, and the problems are particularly significant for 'large' rivers and basins, and hence some water bodies can be designated 'Heavily Modified Water Bodies' (HMWB).

The Danube is the most international river basin globally, spanning 19 countries, and arguably it is one of the most complex basins in which the WFD and other EU directives have to be implemented. However, in 1994 the Danube River Protection Convention which established the International Commission for the Protection of the Danube River (ICPDR) was signed by 14 countries within the basin (each with >2000 km^2 in the basin). The ICPDR provides the organisational structure that is a pre-requisite to resolving the conflicting pressures of protecting the water environment whilst enabling continued, sustainable, water use within the basin. Our aim is to build upon recent Danube Basin overviews (e.g. Sommerwerk et al., 2009) to consider the scale of the challenges that confront river managers in the Danube Basin, and the need for a tool for knowledge exchange to advance sustainable river basin management. Thus, in this paper we explore current challenges in the integrated management of the Danube River Basin (DRB). We do this by describing and identifying: (1) pressures due to river engineering; (2) hydromorphological implications of engineering works; and (3) case studies of the current status of the Danube River.