Source to mouth sediment budget of the Rhine River – Contributions to river basin management

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Introduction: Integrated sediment management requires to study river morphology for various grain sizes on the basin-scale. Sediment budget analysis is a tool for studying morphological processes and connectivity of different river reaches and compartments.
Within the project "Sediment budget of the Rhine, from source to mouth", we carried out a unique, detailed, basin-wide, fraction-wise, morphological analysis of the Rhine by means of a sediment budget analysis.

Methods: A sediment budget is the mass balance between the sediment input (I), output (O) and storage (ΔS) of an area of interest in a period of time: $I - O = \Delta S$. Sediment budgets account for the sources, transport paths and sinks in geomorphic systems. We adopted the sediment budget approach to synthesize existing studies and data, in order to obtain a coherent morphological view on the Rhine basin. In this study, the main channel of the Rhine is the area of interest. A sediment budget was established for four grain size fractions (clay/silt, sand, fine gravel, coarse gravel/cobbles), for the period between 1991 and 2010. The Rhine was divided into eight sections with variable geographical settings, covering the complete length of the Rhine. The sediment budget allowed to identify the major sediment sources and sinks of various size fractions and to calculate mean annual sediment fluxes along the longitudinal profile from source to mouth.

Results: Results show that sediment fluxes in the Rhine are discontinuous due to human and natural causes. On a basin-scale, nourishment represents the biggest source of gravel and cobbles, and tributaries the biggest fluvial source of clay, silt and sand. In the lower Rhine delta, additionally large amounts of clay, silt and sand are supplied by the sea. Dredging represents a main sediment sink for all size fractions. For silt and clay, also floodplain deposition and deposition in ports represent major sinks. Sediment fluxes in the Rhine are strongly influenced by river training works from the past, as well as by present-day dredging and nourishment operations. Nevertheless, natural factors determine the large-scale locations of main sedimentation areas. The behavior of the clay/silt, sand and gravel/cobble fractions strongly differ from each other. Particularly, in many reaches gravel is deposited, whereas sand is being eroded simultaneously. The budget analysis shows that sediment dynamics in rivers are much higher than is suggested by echosoundings or transport measurements, and it also shows that sand plays a dominant role in the morphodynamics of the Rhine, not only in the sand-bed reaches, but also in the gravel-bed reaches of the river.

Discussion: The sediment budget of the Rhine sheds light on sources and sinks of sediments and helps to identify causes of changes in sediment fluxes. This knowledge supports optimal management strategies, e.g. dredging operations, and helps to identify positive and negative implications of anthropogenic influence on the sediment budget. Our study highlights uncertainties in data or gaps in data acquisition and helps to improve the sediment monitoring of the Rhine. The explanatory power of the Rhine sediment budget depends on the applied temporal and spatial scale. The presented analysis of the Rhine does not allow for the identification of short-term morphological processes (e.g. caused by floods), nor for the identification of long-term processes (e.g. caused by climate change).

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References: [1] Hillebrand & Frings (eds.) (2017) *Report No-II-22 of the CHR* (in prep.).