From source to mouth: the sediment budget of the river Rhine

**Roy Frings**\(^1\), Nicole Gehres\(^2\), Gudrun Hillebrand\(^3\), Stefan Vollmer\(^2\), Holger Schüttrumpf\(^4\)
\(^1\)Institute of Hydraulic Engineering and Water Resources Management, RWTH Aachen University, Aachen, Germany
\(^2\)Department of Groundwater, Geology and River Morphology, Federal Institute of Hydrology, Koblenz, Germany

**Background**

The Rhine (Fig. 1) is the most important waterway in Europe. It is subject to severe erosion and sedimentation, causing problems for e.g. navigation, flood safety and ecology.

For sound river management, information is needed on (1) the size of the sediments that are moving, (2) the sources and sinks of these sediments, (3) the mechanism and magnitude of the sediment transport. This information can only be obtained through sediment transport measurements in combination with a sediment budget analysis (Fig. 3).

**Objective**

The objective of this research project is to establish a sediment budget for the entire Rhine catchment, starting at the source in Switzerland and extending to the mouth in Netherlands (Fig. 1, 2). This implies quantification of the downstream fluxes of sediments, (3) the mechanism and magnitude of the sediment transport. This information is necessary for sound river management, information is needed on the sediment exchange between the river bed, floodplains and groyne fields, which is likely to reduce erosion rates in future.

**Study Area**

The Rhine has a drainage basin of 197,000 km\(^2\), covering 5 geological zones (Fig. 2). Its length is 1230 km and its discharge regime partly snow-melt and partly rain dominated. The mean discharge at the German-Dutch border is 2300 m\(^3\)/s. For most of its length, the Rhine is heavily engineered (Fig. 1) banks are protected with groynes, shipping routes are constantly being dredged and embankments prevent flooding of the densely populated areas near the river.

**Methods**

During the project duration (2012-2015) existing data on sediment fluxes, sources and sinks will be reanalysed, whereas essential, but hitherto missing data on the sediment input from tributaries and the exchange of channel sediment with floodplains and groyne fields will be gathered. We focus on the time period 1991-2010.

**Results**

Up to now, a sediment budget analysis has been carried out for the German Lower Rhine, a 225 km long reach of the Rhine (area 4 in Fig. 2), focusing on gravel and sand. Echosoundings indicate an average bed degradation of 3 mm/a between 1991 and 2010 (Fig. 5a). This bed degradation represents a major term of the sediment budget (Fig. 4). Sediment sources are: the sediment supply from upstream (Fig. 5b) and the artificial feeding of sediment (mostly gravel) by river managers to reduce bed degradation (Fig 5c). Sediment inputs by tributaries and bank erosion are assumed negligible. Sediment sinks include net dredging activities (Fig. 5d), abrasion and the sediment output to the downstream area (Fig. 5b). Although no data on floodplain deposition exist, a significant deposition of sand on the floodplains and in the groyne fields has to be assumed in order to close the budget (Fig. 4).

**Discussion & Conclusions**

The causes for the bed degradation in the study area are o.a. the river training works from the past, an insufficient sediment supply from upstream and subsurface sediments consisting of fine Tertiary sand (Fig. 5f). The erosion of sand leads to bed coarsening (Fig. 5e) or armouring, which is likely to reduce erosion rates in future.

**Project Funding**

The Ministry of Transport, Building and Urban Development, Germany

**Contact Information**

Frings@www.rwth-aachen.de
Gehres@bafg.de

**Invitation**

International cooperation is a prerequisite for success in this project. If you are interested in cooperating with us, please feel welcome to contact us.

---

**Fig. 1. The Rhine river from source to mouth:** (a,b) Alps with Molasse, 2. Upper Rhine Graben, 3. Rhenish Massif, 4. Delta. (Photo courtesy: F. Knopp, Cordula Unterberg, Rühl, G. Geller-Grimm, Rijkswaterstaat, M. Minderhoud).

**Fig. 2. Topography and geology of the Rhine basin (Frings et al. in prep., modified from DHR, 1978). Major tectonic units: 1. Alps with Molasse, 2. Upper Rhine Graben, 3. Rhenish Massif, 4. Lower Rhine Embayment, 5. North Sea Basin.**

**Fig. 3. The sediment budget approach, representing the balance between the sediment amounts entering the study area (\(I_i\), Mt/a), leaving the study area (\(O_i\), Mt/a) and being stored in the study area (\(S_i\), Mt/a). \(\Delta S = \sum (I_i - O_i - S_i)\).**

**Fig. 4. Sediment budget for gravel and sand for the studied part of the Rhine (the German Lower Rhine) for the Period 1991-2010. 100% equals 1.3 Mt/a. Source: Frings et al. (2012).**

---

**Fig. 5. Downstream variation in bed level change (\(\Delta z\)), sediment transport (\(S\)), artificial sediment supply (\(O\)), dumping and dredging (\(D\)), bed grain size (\(e\)) and geology (\(G\)).“After: Frings et al. 2012).**