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Transient response regarding bed elevation and surface texture in the Rhine River

Astrid Blom (1), Antonios Emmanouil (1), Meles Siele (1), and Enrica Viparelli (2)

(1) Faculty of Civil Engineering and Geosciences, Delft University of Technology, Netherlands, (2) Department of Civil and Environmental Engineering, University of South Carolina, Columbia, SC, USA

Over the past few centuries the Rhine River has been severely impacted by river training: the construction of levees has strongly reduced floodplain area, groynes have narrowed the main channel, and river bend straightening has reduced vessel sailing distance in various places. Both levees and groynes prevent the river planform from adjusting to these changes as well as to possible changes of the controls (i.e. the flow rate and its variability, the average gravel and sand flux, and base level). This implies that an engineered river such as the Rhine River can only respond to the above changes by (a) slope adjustment through channel tilting and (b) adjustment of the bed surface texture. In an engineered river, channel narrowing typically leads to a decrease of the equilibrium channel slope, as in a narrower channel a smaller slope suffices to transport the sediment flux downstream. The main channel of the Rhine River degrades at a rate that varies spatially (between a degradation rate of 3.3 cm/a and an aggradation rate of 1 cm/a), and the bed elevation in the upstream Dutch Rhine delta has decreased by 1 to 3 meters over the past century. Navigation becomes increasingly hindered by manmade and natural channel reaches that do not degrade and the stability of structures is at risk. A neglected origin of the bed degradation in the Dutch Rhine is the temporal coarsening of the sediment flux. Within a matter of 20 years the upstream Dutch Rhine has changed from a sand-bed river into a gravel-bed river. Here we assess the bed degradation and surface coarsening in the Rhine River, and discuss the role of sediment nourishments, dredging, dams, present-day measures, Holocene and Pleistocene deposits, and sea level rise.