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Development of an integrated sediment transport model and application at a large gravel bed river

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This paper presents the development, validation and application of iSed, an integrated numerical sediment transport and morphology model. The model was specifically designed to suit the needs of large gravel bed rivers, such as the Danube East of Vienna. It is coupled with external 2-D or 3-D hydrodynamic codes to obtain the flow field and bed shear stress patterns driving sediment transport processes. This approach is of particular advantage for an investigation into sediment dynamics based on hydrodynamics of different dimensionality. The model is capable of calculating both suspended and bed load transport. It solves a convection-diffusion equation to account for suspended load; in addition, four different transport formulae – the relations of Meyer-Peter/Müller, Hunziker, van Rijn and Egiazaroff – are implemented for the computation of bed load. The well-known Exner equation is solved for deriving resulting bed level differences for every node of the computation mesh based on the sediment balance. All equations are evaluated for an unlimited number of sediment size fractions, allowing for the investigation of sorting processes. The river bed is organized into an active layer, where sorting takes place, and an unlimited number of bed layers below the active layer.

The sediment transport model was validated using results from three different laboratory experiments: (i) morphodynamics of a 180 degree channel bend, based on hydraulics of a 3-D numerical model; (ii) erosion and deposition patterns due to a channel contraction, using a 2-D model to provide the flow field; (iii) incipient motion and erosion processes due to different sediment materials in a straight laboratory channel, coupled with a 3-D numerical model. The results of the numerical code were in satisfactory agreement with the experimental measurements, demonstrating the general validity of the sediment transport model.

After successful validation, the model was applied to a 4 kilometre reach of the Austrian Danube East of Vienna. This stretch, situated in a National Park, is characterized by a number of problems, for instance: ongoing river bed erosion is taking place as sediments are retained in upstream reservoirs and the regulated river's reduced width leads to an increased transport capacity, additionally no side erosion can contribute to the sediment balance due to embankment structures; insufficient water depths are available for navigation during low flow periods; and a number of ecological deficits are induced by engineering structures, such as training works, groynes or embankments. Most of these engineering structures were constructed during the major Danube River regulation scheme of 1875. Hence, an integrated river engineering project was established that aims for a mitigation of the present problems.

In the scope of the monitoring task of this project, sediment transport and morphodynamics were computed for four steady-state discharges from regulated low flow up to a 100-year flood and one unsteady flood event, using the numerical model presented. Bed load transport was calculated using a nonuniform formulation of the Meyer-Peter/Müller equation featuring a hiding-exposure correction. The formula was calibrated on data obtained through bed load sampling by basket samplers at various discharges. The convection-diffusion equation governing suspended sediment transport was calibrated using measurements taken with a US P-61-A point integrating suspended sediment sampler at various cross-sections during several different runoffs.

A major result of the numerical modelling of sediment transport at the Danube River is that the nonuniform formulation of transport processes implemented in the model predicts non-zero bed load transport, predominantly of finer material, even at low discharges. This is entirely consistent with the in-situ measurements but clearly contrasts the commonly applied uniform sediment formulae, which have been found to show almost no bed load transport at runoffs lower than mean annual flood. In addition, it was found that the resulting transport rates are very sensitive with regard to the hiding-exposure coefficient applied. An important insight of the present study is therefore that sediment transport and resulting morphodynamics in a large gravel bed river such as the Danube can only be predicted correctly when taking into account sediment size fractions and hiding-exposure effects.