ABSTRACT

A hydro-morphological numerical model with the sediment balance concept has been developed and applied to a reach of the Saalach River. The model results are used to estimate an optimized sediment management strategy in the river.

1 INTRODUCTION

Historical river straightening and the construction of hydropower plants (HPP) or other structures changed rivers worldwide. River engineering measures deal long time only with hydraulic quantities like flood protection and water level regulation. However, research shows that the hydraulic condition of a river cannot be studied alone but the morphology must also be considered, as this produces feedback on the hydraulics [1-3]. As a result, from river training, morphological problems arose, like riverbed degradation, side or embankment erosion or vice versa sedimentation. These can lead to problems for the flood discharge capacity of the river or lowers the storage capacity of reservoirs. For several rivers, sediment management strategies and sediment balances have been developed already to analyze the morphological situation and provide solutions for a sustainable river management [4-6].

In the present study, we analyzed a lower part of the Saalach River, an alpine river in the southeastern part of Germany. This river shows all the before mentioned problems, especially the considerable interaction between the river and river construction works. In the study area, the river has lost its former, meandering character and was forced into a straight trapezoidal channel. The historical and still performed river training (e.g. constructing and operating of HPPs or other barriers) highly unbalances the rivers sediment budget. This results in river bed degradation and erosion to finer sediment layers, which affects the stability of the embankments and the ecological status of the ecosystem. In fig. 1 the strong erosion tendency is shown for instance. At this location, the riverbed is around 4.5 meters deeper than its initial level after 80 years.

As a countermeasure, the authorities perform an artificial sediment transfer at the dam Kibling (rkm 20.6) otherwise all incoming sediment could be trapped in the reservoir of the dam and not available for the downstream reaches. With a certain supply rate, the natural sediment capacity of the river should be satisfied and an equilibrium state achieved. This measure started in 1999 and was performed until 2013 with an average rate of 50,000 m³a⁻¹ (which is lower than the natural incoming sediment load of approx. 80,000 m³a⁻¹). However, the definition of the annual supply rate is a critical point as this is influenced by several factors like annual flood magnitude and frequency, the operation of the downstream run-off-river HPPs and the grain size distribution of the supplied material.

In the last years, some unwanted deposition occurs along the river, especially close to the HPP Rott (rkm 2.4), which has negative consequences for the flood capacity of the river. In 2013, an extreme flood event happened in this reach, with a statistical return period of more than 100 years, and caused a severe flooding of the German foreland. This was the first flooding in this region, favored by a relative high river bottom. In 2005 and 2006, two slightly smaller flood events occurred, but passed this region without harm, because the riverbed was lower than in 2013. A critical point in the river system is the HPP Rott as this delimits the sediment consistency although sed-
iment flushing of the reservoir is performed regularly.

In this study, we developed a numerical hydro-morphological model to analyze the river from the unregulated weir Zollhauswehr (rkm 8.0) to the HPP Rott (rkm 2.4) and find an improved weir operating regulative to increase the sediment capacity. The applied modeling software is the two-dimensional shallow water model Telemac2D, coupled with the corresponding sediment module Sisyphe. The morphological module is extended with developments of the Chair of Hydraulic and Water Resources Engineering, which improves the representation of fractional sediment transport and the interaction with the riverbed [7]. The applied software is full MPI-parallelized, which allows performing the simulations on high-performance-computers (HPC) using multi-cores. This drastically decreases the computational time and allows simulating several years without simplifications (e.g. cutting low discharges).

A special focus is given on the accurate definition of the morphological boundaries for modeling the sediment distribution coming into the study domain over time. Here a one-dimensional mass-balance approach is applied to the upstream river reach from rkm 20.6 to 8.0 including all sediment sources and sinks, as well as changes in the bathymetry along the river reach. In equation (1) the basics of this balance are stated:

\[
QS_{\text{out}, \text{rkm 8.0}} = \Delta V_{\text{20.6}-\text{8.0}} + QS_{\text{in}, \text{rkm 20.6}}
\]

where \(QS_{\text{in}, \text{rkm 20.6}}\) = sum of the annual sediment supply rate at rkm 20.6 over the observation period (m³); \(\Delta V_{\text{20.6}-\text{8.0}}\) = sediment volume change in the domain (m³) and \(QS_{\text{out}, \text{rkm 8.0}}\) = the total output from the domain at rkm 8.0 (m³). The volume change is hereby derived from the temporal change of the mean bottom level of the riverbed cross-sections considering the bed porosity. The calculated sediment output defines the input for the numerical model starting at rkm 8.0. This total load is therefore transferred to a continuous temporal sediment graph using sediment-rating curves and continuous discharge measurements.

With this methodology, we calibrated and validated the model from 01.2006 to 31.12.2013 considering the observed water levels at high water events and measured cross-sectional profiles. Further, the calibrated model was applied for over ten years under the given sediment supply conditions to evaluate the development of the river and to estimate an equilibrium sediment supply. Finally, we propose a new weir operating regulative at the HPP Rott to increase sediment flux through the reservoir. The modeling techniques used in this study can be applied to other rivers with similar problems.

2 ACKNOWLEDGE

The authors would like to thank the Leibnitz-Supercomputing-Center Garching, Germany, for providing an HPC system to perform the simulations for this research. Furthermore, we would like to thank the Wasserwirtschaftsamt Traunstein, Germany, for the data on the study site.

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