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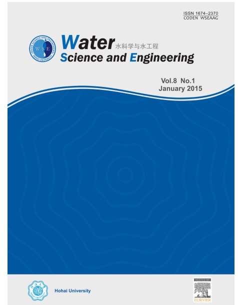

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Comparison of depth-averaged concentration and bed load flux sediment transport models of dam-break flow

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Abstract

This paper presents numerical simulations of dam-break flow over a movable bed. Two different mathematical models were compared: a fully coupled formulation of shallow water equations with erosion and deposition terms (a depth-averaged concentration flux model), and shallow water equations with a fully coupled Exner equation (a bed load flux model). Both models were discretized using the cell-centered finite volume method, and a second-order Godunov-type scheme was used to solve the equations. The numerical flux was calculated using a Harten, Lax, and van Leer approximate Riemann solver with the contact wave restored (HLLC). A novel slope source term treatment that considers the density change was introduced to the depth-averaged concentration flux model to obtain higher-order accuracy. A source term that accounts for the sediment flux was added to the bed load flux model to reflect the influence of sediment movement on the momentum of the water. In a one-dimensional test case, a sensitivity study on different model parameters was carried out. For the depth-averaged concentration flux model, Manning's coefficient and sediment porosity values showed an almost linear relationship with the bottom change, and for the bed load flux model, the sediment porosity was identified as the most sensitive parameter. The capabilities and limitations of both model concepts are demonstrated in a benchmark experimental test case dealing with dam-break flow over variable bed topography.

Keywords: Shallow water; Sediment transport; Bed load flux model; Depth-averaged concentration flux model; Dam break

1. Introduction

Sediment transport in flowing water is one of the main factors in erosion and deposition processes. The mathematical and numerical modeling of these processes is challenging, because the erosion and deposition processes lead to a time-variable bottom elevation, which in return influences the flow. In addition, the sediment concentration is often considered to influence the momentum of the water. Furthermore, the erosion and deposition processes are usually described by empirical laws that depend on several parameters.

Guan et al. (2015) state that there are currently four types of sediment transport models. Two of them are so-called coupled models that solve the hydrodynamic and morphodynamic equations together. Based on the transport mode, coupled models can be categorized into the depth-averaged concentration flux model (CF model) and the bed load flux model (BF model). The other two types of models are so-called decoupled models, namely the two-layer transport model and the two-phase flow model.

In this paper, coupled models are considered. The BF model solves the depth-averaged shallow water equations together with the Exner equation, which describes the sediment transport based on bed load movement through a power law of flow velocity. The interaction between flow and sediment is accounted for by a variable parameter (Murillo and García-Navarro, 2010). Existing literature about the Exner equation treats the hydrodynamic and sediment mass conservation separately, without considering the influence of sediment movement on hydrodynamics (Soares-Frazão and Zech, 2011; Hudson and Sweby, 2003; Liu et al., 2008; Liang, 2011). This model assumes that the movement of the sediment is much slower than the flow velocity. The CF model describes the sediment transport as a fully mixed suspended load, while the erosion and deposition processes are calculated with empirical equations. The sediment is modeled as a concentration in the water column, and its fluxes are calculated based on this concentration. Several additional parameters are introduced to calculate mass exchange between the dissolved sediment and the bed. In this study, source terms were introduced accounting for the interaction between the sediment and flow (Cao et al., 2004;

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