Combining turbulence and mud rheology in a numerical 3D-model of the Ems Estuary

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Introduction

The Ems Estuary is located at the North Sea between Germany and the Netherlands. In the upstream part of the estuary fluid mud layers of thicknesses of around 2m and suspended sediment concentrations of up to 300kg/m³ can be observed (Schrottke, 2006). As a consequence, there are deteriorating environmental conditions and high maintenance costs. Further knowledge of the system behaviour of the Ems Estuary is required in order to understand the increasing siltation and to analyse and develop possible counter measures.

The flow regime of muddy estuaries such as the Ems Estuary is dominated by cohesive sediment transport in transition of low concentrated suspension, high concentrated suspension and fluid mud layers (Fig. 1). The viscous behaviour of water (Newtonian fluid) can be described by turbulence models and the viscous behaviour of fluid mud (non-Newtonian fluid) can be described by rheological models. The rheological characteristics of fluid mud are dependent on the structural behaviour of the material, e.g. break-up and recovery of aggregates under the influence of shear impact (Toorman, 1997). In Knoch and Malcherek (2011) a numerical method was presented which enables the simulation of non-Newtonian flow behaviour in an isopycnal model (layers of constant density). However, in order to describe the dynamics of muddy estuaries a continuous transition from fluid mud to high concentrated suspension to low concentrated suspension with free turbulence is required.

Therefore, the continuous modelling concept (Le Hir *et al.*, 2001; Toorman, 2002; Roland *et al.*, 2012) combining turbulent viscosity and rheological viscosity will be applied. The methods and results of the modelling approach applied to a 3D model of the Ems Estuary will be presented and discussed at the conference.

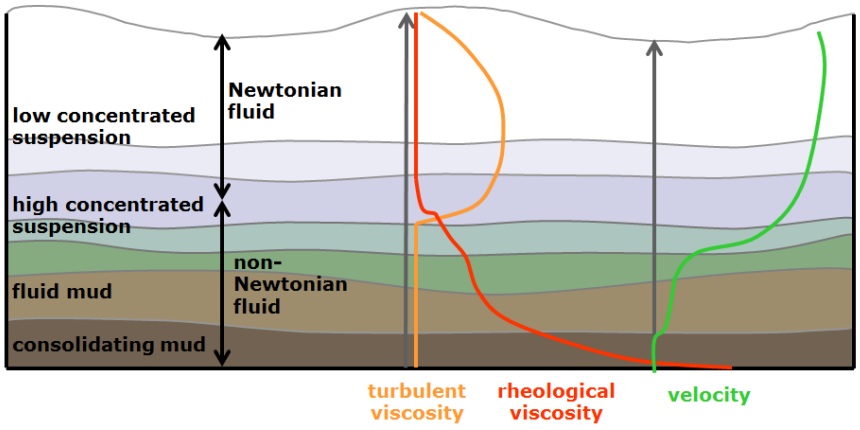

Fig. 1. Schematic diagram of turbulent viscosity and rheological viscosity depending on the sediment concentration (modified from Wehr, 2012).

Methods and Results

An established 3D hydrodynamic model including suspended sediment transport, salt transport and two-equation turbulence models with turbulence damping due to stratification (Casulli and Lang, 2002) will be extended by a rheological viscosity. Different expressions for the rheological viscosity can be applied in accordance with rheological constitutive laws, e.g. Worrall-Tuliani fluid. As a first step, the vertical viscosities are assumed to be the sum of rheological viscosity ν_r and turbulent viscosity ν_t:

$$\nu^v = \nu_t + \nu_r$$

This approach will be applied to the 3D model of the Ems Estuary (Fig. 2). The results will be compared to flied measurements. Moreover, a comparison of the results with numerical simulations of different methods (classic Newtonian and isopynical non-Newtonian) will be performed.

Fig. 2. Satellite image and model domain of the Ems Estuary.

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