NEAR-BED TURBULENCE EFFECT ON DIFFUSIONAL MASS TRANSFER THROUGH A BENTHIC BOUNDARY LAYER INTO AQUATIC SEDIMENT

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Diffusional mass transfer at the sediment/water interface, e.g. dissolved oxygen (DO) uptake, phosphate release or sulfate uptake, can affect the water quality and ecology of a lake, river impoundment or reservoir significantly. The mass transfer rate at the sediment/water interface can depend on near-bed turbulence above the sediment surface. To quantify the vertical diffusive mass flux at the sediment/water interface it is therefore necessary to estimate near-bed turbulence. Two-equation turbulence models, e.g. the k-ε model (Rodi, 1993), have previously been applied to the prediction of near-wall turbulence. Two such models have been applied by Myong, Kasagi and Hirata (1987), and Nagano and Tagawa (1990) to reproduce the limiting behavior of turbulence near a wall for the prediction of heat transfer. For diffusional mass transfer, Dade (1993) investigated the turbulent kinetic energy balance of shear flow, and proposed a formula for near bed turbulence prediction. We have previously used Dade's formula for SOD estimation (Higashino et al., 2003). The purpose of this paper is (1) to show that Dade's formula predicts near-bed turbulence, i.e. distributions of eddy diffusivity/viscosity, as well as the k-ε turbulence models, and (2) to show that simulation results obtained with Dade's formula, e.g. for solute concentration profiles near the sediment/water interface or for diffusive boundary layer thicknesses (Higashino et al., 2003), compare favorably with those obtained by other turbulence models and in experiments (Steinberger and Hondzo, 1999). These turbulence models, i.e. Dade's formula, the Myong/Kasagi/Hirata (MK) model, and the Nagano/Tagawa (NT) model, have in common a physically significant feature: Eddy diffusivity changes with distance from the wall cubed.

Without explicit specification of the strength of the material sink in the sediment, the predicted diffusive flux across the sediment/water interface, i.e. the Sherwood number (*Sh*), tends to depend on the near-bed turbulence, when the Schmidt number is larger than 10, which is the case for most water soluble substances. Sherwood numbers calculated by the NT model are smaller than those calculated by Dade's formula and the MK model; the ratio is approximately 1.7. Diffusive boundary layer thicknesses predicted by the NT model match measurements best, but the MK model and Dade's formula also give reasonable results.

The strength of the material sink in the sediment layer can also be specified by the kinetics of the chemical or biological processes involved. For example oxygen uptake by the sediment layer includes a sink due to microbial activity in the sediments, which can be specified by Monod growth kinetics. In that case the simulated SOD values are virtually identical for all three turbulence model used in this study, except when shear velocity is low, i.e. U_*<0.5cm, and microbial activity inside the sediment is high, i.e. X_{max}>100mg/l. Even then the SOD predictions with the NT model are only 20% lower. The prediction of near-bed turbulence is important for SOD estimation, but the difference between the three near-bed turbulence models used is of no consequence. The reason for this important result is that SOD depends not only on the near-bed turbulence but also on the strength of microbial activity (expressed by the potential biomass X_{max}) inside the sediment. The three turbulence models which quantify the limiting behavior of turbulence near the sediment bed, i.e. Dade's formula, the MK model, and the NT model, are equally appropriate for SOD estimation.