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Modelling transverse turbulent mixing in a shallow flow by using an eddy viscosity approach

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The mixing of contaminants in streams and rivers is a significant problem in environmental fluid mechanics and rivers engineering since to understand the impact and the fate of pollutants in these water bodies is a primary goal of water quality management. Since most rivers have a high aspect ratio, that is the width to depth ratio, discharged pollutants become vertically mixed within a short distance from the source and vertical mixing is only important in the so-called near-field. As a rule of thumb, neutrally buoyant solute becomes fully mixed vertically within 50-75 depths from the source. Notably, vertical mixing analysis relies on well-known theoretical basis, that is Prandtl mixing length model, which assumes the hypothesis of plane turbulent shear flow and provides theoretical predictions of the vertical turbulent diffusivity which closely match experimental results.

In the mid-field, the vertical concentration gradients are negligible and both subsequent transverse and longitudinal changes of the depth-averaged concentrations of the pollutants should be addressed. In the literature, for the application of one-dimensional water quality models the majority of research efforts were devoted to estimate the rate of longitudinal mixing of a contaminant, that is the development of a plume resulting from a temporally varying pollutant source once it has become cross-sectionally well-mixed, in the far-field.

Although transverse mixing is a significant process in river engineering when dealing with the discharge of pollutants from point sources or the mixing of tributary inflows, no theoretical basis exists for the prediction of its rate, which is indeed based upon the results of experimental works carried on in laboratory channels or in streams and rivers.

Turbulence models based on the eddy viscosity approach, such as the k-ε model, k-ω and their variation are the most widely used turbulence models and this is largely due to their ease in implementation, economy in computation and, most importantly, being able to obtain reasonable accurate solution with the available computer power. Despite that they also exhibit some shortcomings mainly due to the assumption of isotropic turbulence, whereas turbulence is known to be anisotropic in open-channel flows, recent studies demonstrated that for simplified cases, where mean velocities and bulk mixing properties are needed, RANS-modeling of shallow flows is still appropriate. More generally, the k-ε model may be recommended for a quick preliminary estimation of the flow field, or in situations where modeling other physical phenomena, such as chemical reactions, combustion, radiation, multiphase interactions, brings in uncertainties that overweigh those inherent in the k-ε model itself.

The abstract presents the results of a numerical study undertaken to simulate the transverse mixing of a steady-state point source of a tracer in a 2D rectangular geometry. In the numerical study an approach based on the Reynolds Averaged Navier-Stokes (RANS) equations was applied, where the closure problem was solved by using a turbulent viscosity concept. The influence of different grid geometries located behind the injection point is evaluated and compared with the results previously obtained in the same 2D rectangular geometry without the grid.