Modeling Suspended Sediment Transport in Open Channels

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Abstract
A two-dimensional mathematical model for calculating suspended sediment transport in open channels is presented in this paper. The transport equation for suspended sediment is solved in a vertically dilated coordinate system using a hybrid finite-analytic technique. The model is tested against a variety of analytical solutions, flume measurements and other related computational results. The comparisons reveal that the model predictions are effective and reasonably accurate.

Introduction
The transport of sediments in open channels plays a major role in affecting the engineering application and the water quality. The analyses of the long term degradation downstream from dams, sedimentation in reservoirs, and the generation of local scour holes around piers and inlet structures all require the in-depth understanding of the transport process of suspended sediment. In terms of the water quality concern, it has been found that the sediment resuspension has a measurable effect on water column chemistry. The ability to predict suspended sediment concentrations in water column is very important to improve the understanding of water quality dynamics and biological processes in water bodies. In this study, the transport equation for suspended sediment is solved in a vertically dilated coordinate system using the hybrid finite-analytic technique. The model is tested against a variety of analytical solutions, flume measurements and other related computational results.

Sediment Transport Equation and Boundary Conditions
Using the concept of eddy-diffusivity, the equation governing the vertical variation of the sediment concentration can be written as

$$C_o^{n+1} = \frac{1}{1+G_o}\left[a_{WC}C_{WC}^{n+1} + a_{EC}C_{EC}^{n+1} + a_{SC}C_{SC}^{n+1} + a_{NC}C_{NC}^{n+1} + \frac{1}{\bar{\bar{F}}}\tilde{S} + G_o C_o^{n}\right] \quad (1)$$

where C = sediment concentration; u = horizontal velocity component; v = vertical velocity component; ws = fall velocity of sediment particles; t = time; x, z = horizontal and vertical coordinates; ex, ez = sediment eddy diffusivity in x- and z-directions, respectively. The distribution of the sediment concentration is prescribed at the channel entrance. At the downstream boundary, the sediment concentrations are assumed to reach the equilibrium condition, such that C/x = 0 is satisfied. At the water surface, the net vertical sediment flux is equal to zero. At the channel bottom, the net vertical sediment flux is equal to a prescribed sediment entrainment.

Numerical Method
For numerical computation, the hybrid finite-analytic method (HFAM) is used. The flow domain is discretized into a set of uniform elements (hx = xi - xi-1; hz = zj - zj-1). In a small sub-region [xi-1, xi]�[zj-1, zj+1], the linearized transport equation can be written as

$$C_o^{n+1} = \frac{1}{1+G_o}\left[a_{WC}C_{WC}^{n+1} + a_{EC}C_{EC}^{n+1} + a_{SC}C_{SC}^{n+1} + a_{NC}C_{NC}^{n+1} + \frac{1}{\overline{\overline{F}}}\tilde{S} + G_o C_o^n\right] \quad (2)$$

where the variable coefficients, b, d, e, f and a source term s are defined in the original transport equation. Adopting the one-dimensional discretization solver, the solution of equation (8) at grid point p can be determined as

$$C_o^{n+1} = \frac{1}{1+G_o}\left[a_{WC}C_{WC}^{n+1} + a_{EC}C_{EC}^{n+1} + a_{SC}C_{SC}^{n+1} + a_{NC}C_{NC}^{n+1} + \frac{1}{\overline{\overline{F}}}\tilde{S} + G_o C_o^n\right] \quad (3)$$

where and are coefficients given in Hu (1999).

Results

The present HFAM based sediment transport model is first tested with the cases where the analytical solutions are available. The predicted concentration profiles agree very well with the selected analytical solutions. The computed sediment concentrations are also compared with the laboratory measurements by Wang and Ribberink (1986). The data inputted for the computation are: H = 0.215m, U = 0.56m/s, k = 0.4, u* = 0.034m/s, ws = 0.0065m/s, a = 0.00215m and b = 1.0. The number of vertical grid points is 15 and the grid size in the x-direction is 0.25m. The horizontal velocity profile is assumed to satisfy the logarithmic velocity distribution. The present model predictions also show good agreement with the measured data. The results indicated that the use of a combined parabolic/constant eddy diffusivity profile yields a better prediction in sediment concentration. Comparisons with other experimental and numerical solutions of sediment concentration are also conducted. The HFAM model again demonstrates to be able to compute reliable and accurate sediment concentrations in open channels.

Conclusions

The development of a two-dimensional sediment transport model is described in this paper. The hybrid finite-analytic discretization is formulated to solve the transport equation of the suspended sediment concentration. The scheme provides highly accurate approximations of the advection and diffusion processes. The model is tested against a variety of analytical solutions, flume measurements and other related computational results. The computed results show good agreement with the measured data. The model is demonstrated to be an effective numerical tool to provide accurate and reliable predictions in sediment concentration.

References

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Wang, Z. B., and Ribberink, J. S. (1986) "The validity of a depth-integrated model for suspended sediment transport." Journal of Hydraulic Research, 24 (1), 53-67.

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