3-D Numerical Modelling of Coastal Currents and Suspended Sediment Transport

Lale Balas, Alp Küçükosmanoğlu, and Umut Yegül

Gazi University, Faculty of Engineering and Architecture, Civil Engineering Department
06570 Maltepe, Ankara, Turkey
{lalebal, akucukosmanoglu, uyegul}@gazi.edu.tr

Abstract. A three dimensional hydrodynamic and suspended sediment transport model (HYDROTAM-3) has been developed and applied to Fethiye Bay. Model can simulate the transport processes due to tidal or nontidal forcing which may be barotropic or baroclinic. The Boussinesq approximation, i.e. the density differences are neglected unless the differences are multiplied by the gravity, is the only simplifying assumption in the model. The model is also capable of computing suspended sediment distributions, amount of eroded and deposited sediment. It is a composite finite difference, finite element model. At three Stations in the Bay, continuous measurements of velocity throughout the water depth and water level were taken for 27 days. Model predictions are in good agreement with the field data.

1 Introduction

The activities around enclosed or semi-enclosed coastal areas that have limited water exchange should be carefully planned and detailed researches to understand water circulations and transport processes should be performed. Since field measurements are usually costly and some times impossible due to physical inabilities, application of numerical models becomes more and more important in the simulations of coastal water bodies. Use of three-dimensional models is unavoidable in all cases where the influence of density distribution, or the vertical velocity variations can not be neglected and in the simulation of wind induced circulation [1],[2],[3]. The detailed knowledge of the water motion is very crucial for a reliable prediction of suspended sediment transport [4],[5].

An unsteady three-dimensional baroclinic circulation model (HYDROTAM-3) has been developed to simulate the transport processes in coastal water bodies[6],[7],[8]. The model consists of three components: hydrodynamic, turbulence and suspended sediment transport models. In the hydrodynamic model, full Navier-Stokes equations are solved. The Boussinesq approximation is the only simplifying assumption in the hydrodynamic model. Temperature and salinity variations are calculated by solving the three dimensional convection-diffusion equations. The two equation $k-\epsilon$ turbulence model is used for the turbulence modelling [6],[7]. The three dimensional conservation equation for suspended sediment where the vertical advection includes the particle settling velocity can be written as:

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + w \frac{\partial C}{\partial z} - w_s \frac{\partial C}{\partial z} = \frac{\partial}{\partial x} (D_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y} (D_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z} (D_z \frac{\partial C}{\partial z}) \quad (1)$$

where C: Suspended sediment concentration; u,v,w: Velocity components in x,y,z directions, respectively; D_x , D_y , D_z : Turbulent viscosity coefficients in x,y and z directions, respectively; w_s : Settling velocity.

Solution scheme is a composite finite element-finite difference scheme [6]. The governing equations are solved by Galerkin Weighted Residual Method in the vertical plane and by finite difference approximations in the horizontal plane, without any coordinate transformation. The water depths are divided into the same number of layers following the bottom topography.

2 Model Application to Fethiye Bay

Developed three dimensional numerical model (HYROTAM-3) has been implemented to the Bay of Fethiye. Water depths in the Bay are plotted in Fig.1. The grid system used has a square mesh size of 100x100 m. Wind characteristics are obtained from the measurements of the meteorological station in Fethiye for the period of 1980-2002. The wind analysis shows that the critical wind direction for wind speeds more than 7 m/s, is WNW-WSW direction.

Fig. 1. Water depths (m) of Fethiye Bay where +:Station I, •:Station II,* : Station III

Some field measurements have been performed in the area. At Station I and at Station II shown in Fig.1, continuous velocity measurements throughout water depth, at Station III water level measurements were taken for 27 days. Simulated velocity profiles over the depth at the end of 8.5 days are compared with the measurements taken at Station I and Station II and are shown in Fig.2.

At the end of 8.5 days of simulation, for Station I, the root mean square error is 0.417 cm/s and bias is -0.095 cm/s. and for Station II, the root mean square error is 0.182 cm/s and bias is -0.027 cm/s. Comparison of results is encouraging. Model well simulates the measurement period. Predicted sediment distributions in the Bay are given in Fig.3. at the end of 8.5 days of simulation.

Fig. 2. Velocity profiles over the water depth at the end of 8.5 days of simulation, at Station I b) at Station II, where, solid line: simulation, dot: measurements.

Fig. 3. Distribution of suspended sediment concentration at the end of 8.5 days of simulation a) at the sea surface b) at the sea bottom

A sensitivity study of model predictions to bottom friction coefficient is performed and $C_f=0.0026$ provided the best match with the measurements. In the application, measurement period has been simulated and model is forced by the recorded wind. No significant density stratification was recorded at the site. A horizontal grid spacing of $\Delta x=\Delta y=100$ m. is used. The sea bottom is treated as a rigid boundary. Model predictions are in good agreement with the measurements. During the site investigations, it has been observed that suspended sediment concentration is the highest around the island. Inner and outer parts of the Bay are rather dynamic regions where there may occur sediment deposition or resuspension depending on the blowing wind direction. Model simulations well agree to the observed regions at the site. Sediment sampling studies are still in continuation at the site.

3 Conclusions

A baroclinic three dimensional numerical model of transport processes in coastal areas has been presented. The model consists of three components; hydrodynamic, turbulence and suspended sediment transport. The developed model is able to predict suspended sediment concentration profiles, re-suspension of bottom sediments, equilibrium and deposition sites of the coastal area and determines changes in sea bed morphology quantitatively. Model has been applied to Fethiye Bay where there exist some field measurements. Model implementation to Fethiye Bay has provided realistic results and has shown the capability of model to predict complex circulation patterns.

References

1. Olsen, N. R. B.: Two-dimensional numerical modelling of flushing processes in water reservoirs. *Journal of Hydraulic Research* 37(1) (1999) 3-16.
2. Inoue, M., Wiseman Jr. W. J.: Transport mixing and stirring processes in a Louisiana Estuary: a model study. *Estuarine Coastal and Shelf Science* 50(2000) 449-466.
3. Li, C.W, Gu, J.: 3D Layered-Integrated Modelling of Mass Exchange in Semi-Enclosed Water Bodies. *Journal of Hydraulic Research* 39(2001) 403-411.
4. Lin, B., Falconer, R.A.: Tidal Flow and Transport Modelling Using Ultimate Quickest Scheme. *Journal of Hydraulic Engineering* 123(1997) 303-314.
5. Garcia-Martinez, R., Saavedra, C. I., De Power B. F., Valera E.: A two-dimensional computation model to simulate suspended sediment transport and bed changes. *Journal of Hydraulic Research* 37(1999) 327-344.
6. Balas, L., Özhan, E.: An implicit three dimensional numerical model to simulate transport processes in coastal water bodies. *Int. Journal of Numerical Methods in Fluids* 34 (2000) 307-339.
7. Balas, L., Özhan, E.: Applications of a 3-D Numerical Model to Circulations in Coastal Waters. *Coastal Engineering Journal* 43 (2001) 99-120.
8. Balas, L.: Simulation of Pollutant Transport in Marmaris Bay. *Chinese Ocean Engineering Journal* 15 (2001) 565-578.