Comparison of longitudinal equilibrium profiles of estuaries in idealised and process-based models

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1 Introduction

Morphological developments in complex areas such as estuaries result from complex interaction between water motion, sediment transport and the erodible bed. Various model approaches can be used to investigate the mechanisms behind the morphodynamic evolution (de Vriend, 1996; de Vriend and Ribberink, 1996). In this contribution two types of models, i.e. idealised and process-based models, will be compared.

In recent years much work has been done on width–averaged idealised models. These models give a good insight in the physics that underly morphodynamic processes. They have been used to determine long–term equilibrium profiles (Schuttelaars & De Swart, 1996; Schuttelaars & De Swart, 2000; De Jong, 1998; Van Leeuwen *et al.*, 2000; Lanzoni & Seminara, 2002). Additionally, linear stability analysis was adopted to study the initial formation of channels and shoals in tidal embayments (Schuttelaars & De Swart, 1999; Seminara & Tubino, 2001; Van Leeuwen, 2001). One of the drawbacks of idealised models, however, is that they are limited to idealised geometries. This limitation is absent in a process–based model (Hibma, 2001) using the numerical modelling system Delft3D (Wang *et al.*, 1991) to study the formation of channels and shoals with geometries similar to those used in the analytical models. However, a comparison of the model results appeared to be difficult due to the differences in model description and assumptions.

The objective of this study is to compare and explain the results of an idealised and a process-based model. This process-based model is an adapted version of Delft3D in which the differences between the model formulations are minimised. Step by step these adaptations in the process-based model will be removed. This will give more insight into the processes found in the process-based model on the one hand and into the influences of the assumptions in idealised models on the other hand.

2 Description of the model

Both models describe the water motion by depth averaged shallow water equations. The suspended sediment transport is calculated using an advection-diffusion equation. The formulation used in the process-based model is changed to resemble the model description of the idealised model as close as possible. The changes include the linearisation of the friction term, neglect of the bed-load transport and the formulation for the calculation of equilibrium sediment concentration. The main difference in the description of the water motion concerns the higher order tidal components due to interaction of M_2 and M_4 components, which are neglected in the idealised model and will be maintained in de process-based model. The hydrodynamics and morphological development of basins of various lengths are simulated. In some experiments the initial bottom profile is a linear sloping bed, increasing from 10 m below MSL at the seaward boundary to around HWL at the landward end. In other experiments the equilibrium profiles resulting from the idealised models (see Fig. 1) are used. The lateral and landward boundaries are fixed and impermeable. On the seaward boundary a M_2 water level variation is imposed, with an amplitude of 1.75 m. The bed material consists of uniform sand with $D_{50} = 200\mu m$.

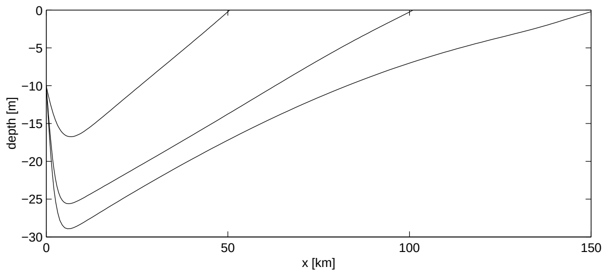

Figure 1: Equilibrium profiles for 50, 100 and 150 km basins.

3 Model results

3.1 Comparison of hydrodynamics

The hydrodynamics resulting from the idealised and process-based models are compared for three different basin lengths. These basins are shorter than (50 km), equal to (100 km) and longer than (150 km) the tidal resonance length (which is approximately 100 km). The M_2 and M_4 tidal components from the time series of the simulations are compared. Figure 2 shows the velocity and water level amplitudes and phases along the 50 km basin, resulting from the two models. For this as well as the larger embayments the hydrodynamics on identical bottom profiles in both models show very good agreement. Small deviations are found near the open boundary and in the shallow area of the basin. Deviations near the open boundary are due to different boundary conditions in the two models. Deviations in the shallow area can be explained by the slightly different formulations of the friction term, which become more significant for smaller depth.

3.2 Comparison of longitudinal profiles

Albeit small, differences in flow field imply that the sediment transport fields and therefore the morphological changes will also deviate. Thus the profiles of the idealised model will not be in equilibrium for the process-based model. For each basin a morphological simulation is made to investigate the tendency of the changes in the profile.

Starting from a linear profile strong erosion near the entrance of the embayment occurs for all embayments. The landward slope is linear for the short basin and becomes more convex for the longer basins. After the simulation period of approximately 1000 years, the

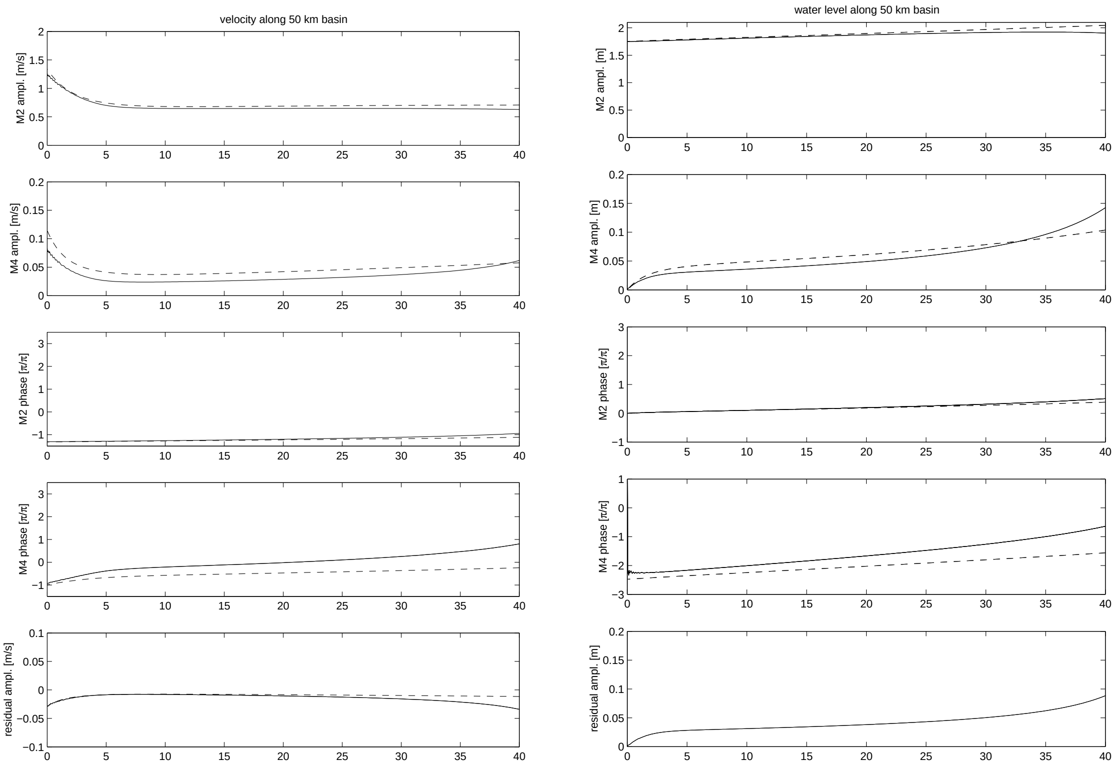

Figure 2: Amplitude and phase of the M_2 and M_4 tidal velocities (left panel) and water levels (right panel) along a 50 km long basin. Solid: process-based model; dashed: idealised model.

developing profiles resemble qualitatively the equilibrium profiles of the idealised model and also quantitatively for the 50 km basin. Starting from the equilibrium profiles of the idealised model, the morphological changes are much smaller, which implies that the deviation from a possible equilibrium profile is smaller. The main changes take place near the entrance of the basin, due to the differences in boundary description for the suspended sediment concentration. In the idealised model, a boundary layer is allowed for in the time-averaged part of the sediment concentration, but not in the time dependent concentration. In the process-based model no distinction is made between the time-averaged and time-dependent parts of the concentration field, and a boundary layer is allowed for the entire (time-dependent) concentration field.
In all cases the morphological changes decrease exponentially during the simulations. However, an equilibrium defined by zero net transport is not achieved during the simulation period.

3.3 Influence of model adaptations

To study the influence of the simplifying assumptions on the longitudinal profiles these assumptions are reversed in the process-based model. Linearisation of the friction term, neglect of the bed-load transport and the differences in formulation of the suspended sediment transport only have a minor influence on the development of the profiles. However, the difference in the boundary condition at the entrance of the embayment results in very different equilibrium profiles. In the idealised model the bottom level at the entrance is fixed independent of the sediment transport direction, wheras in the process-based model the bottom level is only fixed if the residual sediment transport is inwards (Wang, 1990).

4 Conclusion

The results of the idealised and adapted process-based model show good agreement with respect to the water levels and velocities in a schematized estuary. The development of the longitudinal profiles in the process–based model resemble qualitatively the equilibrium profiles of the idealised model, although an equilibrium is not achieved in the strict sense of zero net sediment transport. Quantitative deviations in model result are caused by the different descriptions of the boundary conditions. Furthermore, the model adaptations have no qualitative influence, except for the fixation of bottom at the entrance.

References:

De Jong, K. (1998), Tidally averaged transport models. Ph.D. thesis, Delft University of Technology, The Netherlands.

Hibma, A., H. de Vriend and M.J.F. Stive (2001), Channel and shoal formation in estuaries. IAHR River, Coastal and Estuarine Morphodynamics, p. 463-472.

Lanzoni, S., & G. Seminara (2002), Long–term evolution and morphodynamic equilibrium of tidal channels. *J. Geophys. Res.*, 107, p. 1-13.

Schuttelaars, H.M. and H.E. de Swart (1996), An idealised long–term morphodynamic model of a tidal embayment. *Eur. J. Mech., B/Fluids*, 15(1), p. 55-80.

Schuttelaars, H.M. and H.E. de Swart (1999), Initial formation of channels and shoals in a short tidal embayment. *Journal of Fluid Mechanics*, vol.386, p. 15-42.

Schuttelaars, H.M. and H.E. de Swart (2000), Multiple morphodynamic equilibria in tidal embayments. *Journal of Geophysical Research*, vol.105, no. C10, p. 24,105-24,118.

Seminara, G. and M. Tubino (2001), Sand bars in estuaries. Part 1. Free bars. *J. Fluid Mech.*, 386, p. 15-42

Van Leeuwen, S.M., H.M. Schuttelaars and H.E. de Swart (2000), Tidal and morphologic properties of embayments: effects of sediment deposition processes and length variation. *Phys. Chem. Earth (B)*, 25, p. 365-368.

Van Leeuwen, S.M., and H.E. de Swart (2001), The effect of advective processes on the morphodynamic stability of short tidal embayments. *Phys. Chem. Earth (B)*, 26, p. 735-740.

Vriend, H.J. de (1996), Mathematical modelling of meso-tidal barrier island coasts. Part I: Empirical and semi-empirical models. In: P.L.-F. Liu (ed.), *Advances in coastal and ocean engineering (2)*, 115-149.

Vriend, H.J. de and J.S. Ribberink (1996), Mathematical modelling of meso-tidal barrier island coasts. Part II: Process-based simulation models. In: P.L.-F. Liu (ed.), *Advances in coastal and ocean engineering (2)*, 151-197.

Wang, Z.B. (1990), Some considerations on mathematical modelling of morphological processes in tidal regions, 5th Conference Physics of Estuaries & Coastal Seas.

Wang, Z.B., H.J. de Vriend, and T. Louters (1991), A morphodynamic model for a tidal inlet, The Second International Conference on Computer Modelling in Ocean Engineering.