Modelling river dune development

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Introduction

Since river dunes influence flow resistance, predictions of dune dimensions are required to make accurate water level predictions. A model approach to simulate developing river dunes is presented. The model is set-up to be appropriate, i.e. as simple as possible, but with sufficient accuracy for management purposes. Model results so far are promising.

During floods, dunes develop on the river bed as a result of the interaction between flow and sediment transport (Fig. 1). In the River Rhine, dunes can become 1-2 m in height and up to 50 m in length in a water depth of about 10 m.

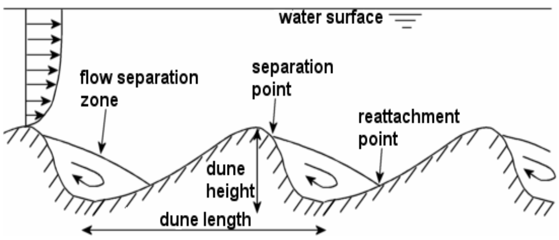

Figure 1. Longitudinal sketch of dunes. Dimensions of dunes and flow separation zones are indicated.

The dynamic behaviour of dunes is not yet completely understood. In our model, we include the processes that we think are most important for dune development, namely: the flow and sediment transport over dunes, and the formation of a wake behind the dunes.

Model for gentle dunes

Although in rivers the flow is uni-directional while at sea reverse flow occurs, driving mechanisms behind dune and offshore sandwave development are more or less similar. Therefore, a physics-based simulation model (Van den Berg & Van Damme, 2005), which is originally developed to simulate the development of offshore sand waves, is calibrated in order to use it under uni-directional flow conditions. The model is based on hydrostatic shallow water equations, with a constant eddy viscosity over depth. The sediment transport equation used includes bed slope effects.

Fig. 2 shows the simulation results under steady flow. Realistic bedform behaviour of dunes with gentle slopes (no flow separation) is obtained: dunes grow in amplitude, become asymmetric and migrate.

During their development, the lee-side of dunes may become so steep that the flow separates behind the dune, because of the adverse pressure gradient. The applied flow equations cannot simulate separated flow.

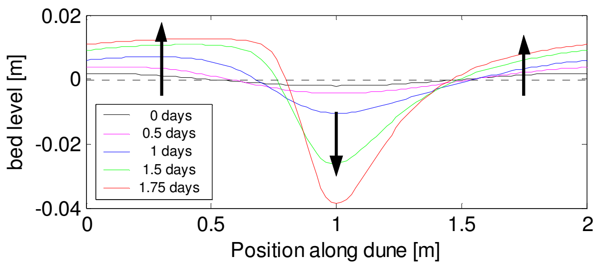

Figure 2. Simulation of dune development starting from a small initial symmetric bed disturbance using flume conditions (waterdepth is 10 cm). The locations of the troughs are "corrected" for migration which is about 4 m/day.

Parameterization of flow separation

To include flow separation, a sophisticated turbulence model like a k-ε model could be used. However, this requires large computational efforts. We need a first model, so in order to keep the model simple we choose to follow the method of Kroy et al. (2002). They parameterize a separating streamline, which is the upper boundary of the flow separation zone. The separating streamline is used as bed level for flow computations. This effectively means that details in the flow separation zone (with flow recirculation) are not computed. Paarlberg et al. (2005) parameterize the separating streamline, using data of turbulent flow over fixed (underwater) bedforms. The derived relationship depends on general dune characteristics. A linear relationship is used to estimate the length of the flow separation zone.

Implementation of the parameterization

Currently, the parameterization of flow separation is being implemented in the model. When the bed slope becomes smaller than -14˚, the flow is assumed to separate (see e.g. Kroy et al., 2002). The separating streamline is determined and the flow is computed using this separating streamline as artificial bed level. Bed evolution in the region of flow separation is computed by updating the original bed, using shear stresses computed over the artificial bed level.

Application of the model

The performance of the model is tested by comparing simulation results to flume experiments with floodwaves of Wijbenga & Van Nes (1986). Since at present our model only simulates steady flow, we compare simulation results, at various moments in time, with the measurements. Fig. 3 shows that the dynamics of dune development are predicted qualitatively by our model.

Conclusions & discussion

With the presented model approach, dune development can be simulated in cases when flow separation occurs, without the necessity of computing details in the flow separation zone. Simulation results show that realistic bedform behaviour can be obtained: dunes grow in amplitude, get asymmetrical in flow direction and migrate. Also dunes that are measured in a flume are reproduced qualitatively. Knowing the dimensions of the dunes and of the flow separation zone, better estimates of the roughness caused by dunes can be obtained. This can help to improve water level predictions.

Future work will focus at the modelling of sediment transport in the flow separation zone and the bed roughness. Other points of attention are the boundary condition required above the flow separation zone, the turbulence (viscosity) model, and the bed shear stress distribution along the dunes.

Acknowledgements

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References

Kroy, K., Sauermann, G., and Herrmann, H. J., 2002. Minimal model for aeolian sand dunes. Physical Review E, 66 (3), 19 p.

Paarlberg, A. J., Dohmen-Janssen, C. M., Hulscher, S. J. M. H., and Termes, A. P. P., 2005. A parameteriza-tion of flow separation in a river dune development model. In: Proceedings of the 4th conference on River, Coastal and Estuarine Morphodynamics. Parker, G. and Garcia, M. H. (eds.), vol. 2, 883-895. Taylor & Francis Group, London.

Van den Berg, J. and Van Damme, R., 2005. Sand wave simulation on large domains. In: Proceedings of the 4th conference on River, Coastal and Estuarine Morphodynamics. Parker, G. and Garcia, M. H. (eds.), vol. 2, 991-997. Taylor & Francis Group, London.

Wijbenga, J. H. A. and Van Nes, A. R., 1986. Flow resistance and bedform dimensions for varying flow conditions; results of flume experiments with flood waves. TOW rivers R 567 - XXV / M 1314 part XIII, WL │ Delft Hydraulics, Delft, The Netherlands.

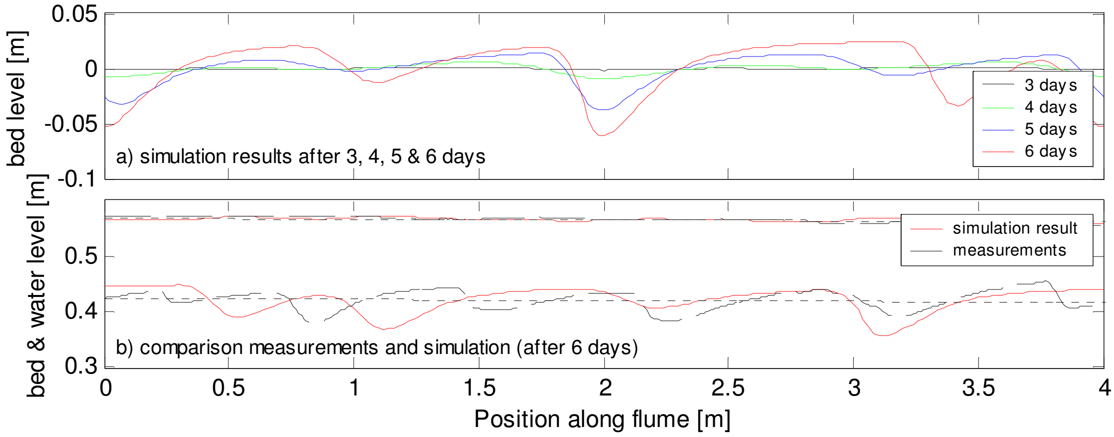

Figure 3. Qualitative comparison of simulation results with measurements. The presented measurement results are taken at an arbitrary moment in time during a flood wave in a flume 30 m long, at a discharge of q=0.034 m^2/s . The steady discharge in the simulation is also 0.034 m^2/s. The average waterdepth is 14 cm.