Modelling pick-up and deposition in a dune model

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Water level forecasts with a high river water discharge depend on accurate predictions of the evolution of river dunes. For flood early-warning systems complexity in sub models is a drawback as it leads to (too) large computation times. Therefore the aim of this study is to develop a relatively simple dune evolution model that works well in the dune regime, and which has the potential to predict the upper-stage plane bed as well.
To reach this goal we will study the influence of using certain bed load transport formulations on the resulting dune morphologies. For this we will investigate whether alternative bed load transport models within the computationally cheap model of Paarlberg et al. (2009) lead to good results.

General model set-up

The basis of the present model is the dune evolution model developed by Paarlberg et al. (2009). Paarlberg et al. (2009) extended the process-based morphodynamic sand wave model of Németh et al. (2006), which is based on the numerical model of Hulscher (1996). Flow, sediment transport and bed evolution are calculated in a decoupled manner.

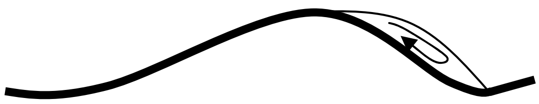

Figure 1. Schematization of a dune (flow left to right).

Flow separation is forced in the model when the leeside slope exceeds 10°. Behind the dune bed shear stress is parameterized using experimental data of turbulent flow over two-dimensional subaqueous bedforms (Paarlberg et al. 2007). In the flow separation zone the bed shear stress is assumed to be zero and all the sand that reaches the crest of the dune is avalanched under the angle of repose on the leeside of the dune (Paarlberg et al., 2009).
The model simulates a single dune with periodic boundary conditions. The domain length and thereby dune length is forced by using a numerical stability analysis as in the original model by Paarlberg et al. (2009).

Bed load transport variants

We use three bed load models: the original, a version with a relaxation equation, and a version with a pick-up and deposition model.

Equilibrium transport model

In the original dune evolution model equilibrium bed load transport is taken into account. This is calculated by applying a formula of the type of Meyer-Peter and Müller (1948) including gravitational bed slope effects.

Linear relaxation of transport

Instead of calculating the equilibrium transport and taking that as the actual transport, the following relation is applied:

$$\frac{dq_b}{dx} = \frac{q_{b;e} - q_b}{\Lambda}$$

where $q_{b;e}$ (m^2/s) is the equilibrium sediment transport as determined above, q_b (m^2/s) is the 'corrected transport' and Λ (m) is the mean step length. This is determined by:

$$\Lambda = \alpha D_{50}$$

where α is the non-dimensional step length (as used by Nakagawa and Tsujimoto, 1980) and D_{50} is the media grain size (m).

Pick-up and deposition model

The pick-up and deposition model of Nakagawa and Tsujimoto (1980) determinespick-up of sediment (probability of a particle being picked up in s^{-1}) with

$$p_s(x) = F_0 \sqrt{\frac{\Delta g}{D_{50}}} \tau_*(x) \left(1 - \frac{\tau_{*c}}{\tau_*(x)}\right)^3$$

where F_0=0.03, $\tau_*(x)$ is the local non-dimensional bed shear stress, $\tau_{*c}(x)$ is the local critical non-dimensional bed shear stress, $\Delta=\rho_s/\rho-1=1.65$ (ρ_s/ρ is the specific grain density) and g is the acceleration due to gravity. To determine the deposition at a certain location x the distribution of picked up sediment from upstream locations is needed. The determination of deposition is done by applying the following formula:

$$p_d(x) = \int_0^\infty p_s(x-s) f(s) ds$$

where the distribution *f(s)* determines the fraction of sediment that is deposited a distance s away from the pick-up point (x-s). The distribution function is defined as follows:

$$f(s) = \frac{1}{\Lambda}\exp\left(\frac{-s}{\Lambda}\right)$$

where Λ is the mean step length. Finally the transport gradient is determined as follows:

$$\frac{dq_b(x)}{dx} = D_{50}\left[p_s(x) - p_d(x)\right]$$

Preliminary results

The reference case used for this study is an experiment done by Venditti et al. (2005). The parameter α is varied between 25 and 300 (slightly larger than the experimentally determined range of 40-240 as reported by Sekine and Kikkawa, 1992). See the table below for experimental data and the model results, and the figure below for just the latter.

With the original model dune length and water depth is predicted well, but the dune height is overestimated by about 33%.

Using linear relaxation leads to a limited suppression of the dune length. The spatial lag decreases the total transport and keeps the lee side angle small, so that no more flow separation occurs. This severely limits the dune growth, leading to a very strong suppression of the dune height. With a stronger lag (non-dimensional step length of 75 and greater) this ‘smearing’ effect is so strong that no more dune growth occurs at all.

The dune height is not suppressed with the pick-up and deposition model. Flow separation still occurs, and so all in all the dune is able to grow like it did with the original model. Even larger values for the non-dimensional step length lead to *increasing* dune growth.

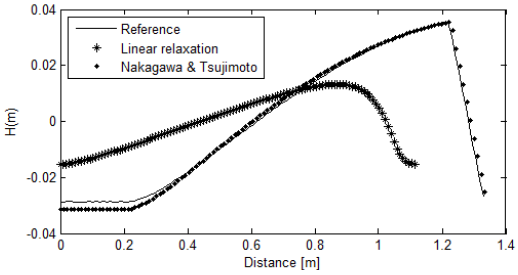

Figure 2. Dune shapes of the three versions, with α=25 for relaxation and pick-up and deposition (flow left to right).

Conclusions and future work

With linear relaxation dunes can be washed out, which makes it a potentially good option for predicting upper stage plane bed. Pick-up and deposition does not, most likely due to how sediment avalanching on the lee side is handled when flow separation is triggered. This will be further studied/improved.

Experiment		
Initial parameters	h_i [m]	0.152
	i [10^{-4}]	12
	q [m^2/s]	0.077
	D_{50} [mm]	0.5
	$\theta_{c;0}$ [-]	0.050
Equilibrium	l_e [m]	1.3172
	Δ_e [m]	0.048
	h_e [m]	0.17

Model results												
MPM	Linear relaxation with α =				Pick-up and deposition with α =							
	25	*50*	*75*	*100*	*25*	*50*	*75*	*100*	*150*	*200*	*250*	*300*
0.064	0.029	0.023	0	0	0.067	0.066	0.064	0.067	0.069	0.07	0.076	0.079
1.33	1.11	1.1	1.07	1.07	1.33	1.33	1.32	1.33	1.34	1.35	1.39	1.41
0.19	0.16	0.16	0.15	0.15	0.19	0.19	0.19	0.19	0.19	0.19	0.2	0.2

Table 1. Used experimental parameters (left) and model results (right).

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