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Book of abstracts

Rivers in an uncertain future

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Modelling morphodynamic changes over fixed layers

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Introduction

A physical process relevant for accurately predicting morphodynamic development in some areas in the Dutch river system such as the bifurcation areas of the Rhine and in the Meuse, is the formation and break-up of immobile sediment layers (a.k.a. fixed layers). Immobile sediment layers develop by vertical sorting processes in the top layer of the bed. Under low-flow conditions, only the finest sediment-size fractions at the bed surface are mobile. Winnowing and transport of fine sediment causes the formation of a layer of coarse sediment over which fine sediment is transported. During high-flow events, these coarse layers can break up, suddenly entraining sediment from below.

Several modelling approaches exist for predicting morphodynamic development under the presence of immobile sediment. However, they present several limitations which limit their applicability range. Here we review the modelling approaches, show the limitations, and develop two possible modelling alternatives that are tested against laboratory measurements.

Existing modelling approaches

Struiksma (1999) modified the Exner equation used for modelling bed level changes under alluvial conditions. He prescribed an alluvial thickness and reduced the sediment transport if the actual sediment thickness above the fixed layer became smaller than the alluvial thickness. This reduction depended on the ratio of actual thickness to alluvial thickness.

Struiksma (1999) conducted flume experiments for testing his approach. A fixed layer of limited length composed of coarse sediment was installed in a fine-sediment bed. A trench was dug upstream. It exposed the fixed layer as it travelled downstream. We modelled the experiments using Elv (Chavarrías et al., 2019). Figures 1, 2, and 3 show the initial condition, an intermediate situation, and the final state using Struiksma's model. Sediment size-fractions 1 and 2 correspond to fine and coarse sediment, respectively.

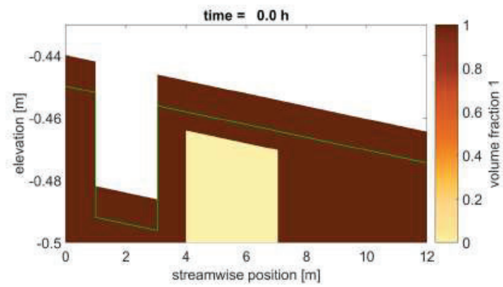

Figure 1: Initial condition.

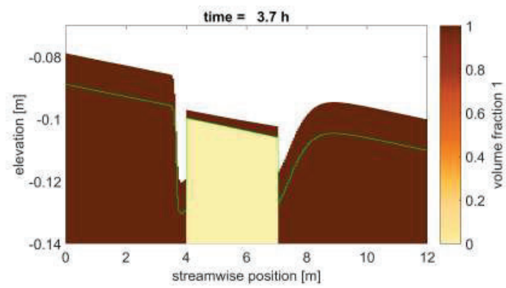

Figure 2: Intermediate state using Struiksma's model.

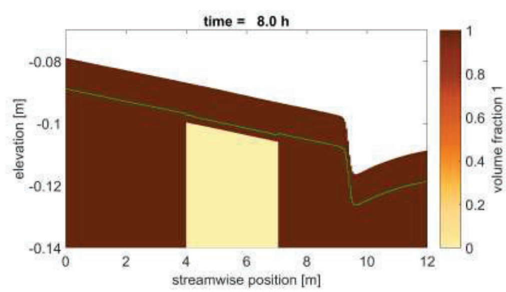

Figure 3: Final state using Struiksma's model.

Struiksma's model can only be used when the sediment forming the fixed layer is never mobile. In order to consider cases in which sediment may become mobile, one can consider using the active-layer model. In this case, as the bed degrades, immobile sediment enters the active layer (Figure 4). Immobile sediment in the active layer reduces the sediment transport rate of fine sediment not only because of

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its presence (i.e., a smaller amount of fine sediment is present at the bed surface) but also due to the hiding-exposure effect. Unfortunately, under aggradational conditions a physically unrealistic process occurs. Sediment in the active layer is equally transferred to the substrate, which causes immobile sediment to be transported upwards (Figure 5).

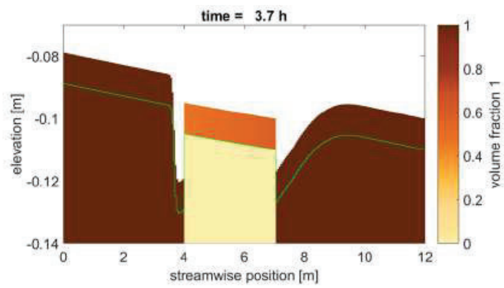

Figure 4: Intermediate state using the active-layer model.

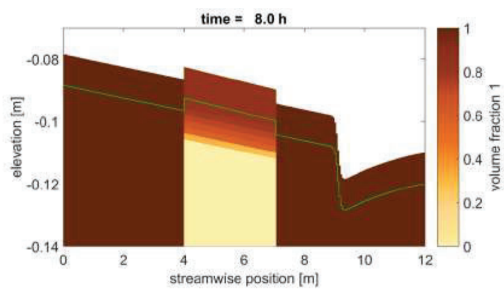

Figure 5: Final state using the active-layer model.

Tuijnder and Ribberink (2010) developed a model for predicting the formation and breakup of immobile sediment layers adding a "coarse layer" below the active layer. The essence of the model is that immobile sediment in the active layer is transferred to the coarse layer. The model, featuring a large number of closure relations and complex fluxes, presents certain limitations and modelling of the same experiment in Delft3D does not fully solve the issue of the active-layer model (Chavarrias et al., 2020).

Model development

We developed two alternatives for modelling morphodynamic development under the presence of sediment that may be immobile. The first one consisted of a modification of the active-layer model in which, under aggradational condition, immobile sediment in the active layer (if any) is preferentially transferred to the substrate. This prevents unrealistic upward transport of immobile sediment. The intermediate state of the experiment is the same as when using the active-layer model and the final state is the same as when using the model by Struiksma (1999).

The second alternative, implemented in Delft3D, is a simplification of the model by Tuijnder et al. rethinking the sediment fluxes. The model behaves as Struiksma's model when modelling the laboratory experiment and allows transport of coarse sediment if this becomes mobile.

Conclusions and future development

Two models have been developed for predicting morphodynamic changes under conditions in which sediment may be immobile. The main difference is that in one of them immobile sediment is allowed to be in the active layer while in the second one it does not enter. Both models correctly reproduce the laboratory experiment by Struiksma. The first one has the benefit that mobile sediment is affected by hiding-exposure. This is also an inconvenience if the difference in grain size is larger than the range of applicability of the usual relations. The second model presents some limitations when, for instance, all sediment becomes immobile.

Probably the first alternative is more realistic and robust, although an improved hiding-exposure relation must be developed for modelling cases in which immobile sediment is significantly larger than the mobile one. Laboratory experiment would be necessary for this development. The models need to be applied to other situations (especially field cases) for clarifying the applicability.

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