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13. A COMMENTARY ON ADVANCES IN MODELLING THE EFFECTS OF VEGETATION ON FLOW, SEDIMENT TRANSPORT AND MORPHOLOGY

13.1 INTRODUCTION

In the planning and design phase of river rehabilitation projects, the use of predictive models can aid in assessing and quantifying the expected outcome. Models that can be applied in this phase are numerical models for hydro- and morphodynamics to assess the future abiotic conditions. One-dimensional numerical models have been applied mainly for this purpose. At present, two- and three-dimensional models are becoming more common in river applications. Two-dimensional models better represent the river topography, the flow fields and the distribution of erosion and sedimentation. Three-dimensional models more accurately model typical hydrodynamic phenomena, for example those that are due to vertical density gradients. A major challenge is to model the interaction of vegetation with flow and morphodynamics.

This paper summarizes three case studies of the application of one-, two- and three-dimensional numerical models to simulate the interaction of flow, vegetation and morphodynamics. In principle, this interaction is twofold. First, river morphology determines factors that control the suitability of locations for specific vegetation to grow and secondly, the vegetation itself affects the flow and transport of sediment, thus changing its environment. One of the first to extensively describe the floodplain vegetation dependence on abiotic factors was Dister (1980). Some more recent studies include Edwards et al. (1999), Bendix & Hupp (2000) and Baumgärter & Grüneklee (2002). The effects of vegetation on flow, sediment transport and geomorphology are of interest to modelling abiotic aspects. Important papers include López & García (1998), Gran & Paola (2001) and Murray & Paola (2003). The interaction between both vegetation (and other organisms) and geomorphology is termed biogeomorphology. Recent papers include: Brown (1997), Hughes (1997), Wolfert (2001), Brooks & Brierley (2002), Gurnell & Petts (2002). This note focuses on modelling the effects of vegetation on their physical environment, i.e. on flow, sediment transport and morphology.

13.2 ONE-DIMENSIONAL MODELLING OF THE RHINE RIVER

This first case study deals with the modelling of flood levels affected by vegetation development and floodplain sedimentation within a 50 km section of the Rhine River in the Netherlands. The objective of this case study is to assess the effects of cyclic floodplain rejuvenation measures on flood levels and biodiversity (Baptist et al., in press). Cyclic floodplain rejuvenation aims to increase the flood conveyance capacity and the biodiversity of floodplains, by mimicking natural rejuvenation processes.

The study used the SOBEK modelling suite for one-dimensional analyses. Floodplain sedimentation and the development and succession of floodplain vegetation were modelled with two separate rule-based models applied in a two-dimensional GIS delivering input to SOBEK. The sedimentation model described the sedimentation rate per inundation day, for various morphological floodplain units. The vegetation model described the succession of vegetation dependent on the local conditions. The model simulation described the effect on the flood levels in the Rhine River of the combination of increasing hydraulic roughness and sedimentation of the floodplain over a period of fifty years. In case the computed water level exceeded the design level for safety in a floodplain section, cyclic floodplain rejuvenation measures were implemented during the simulation. These measures consisted of (combinations of) the removal of floodplain forest and the removal of sediment.

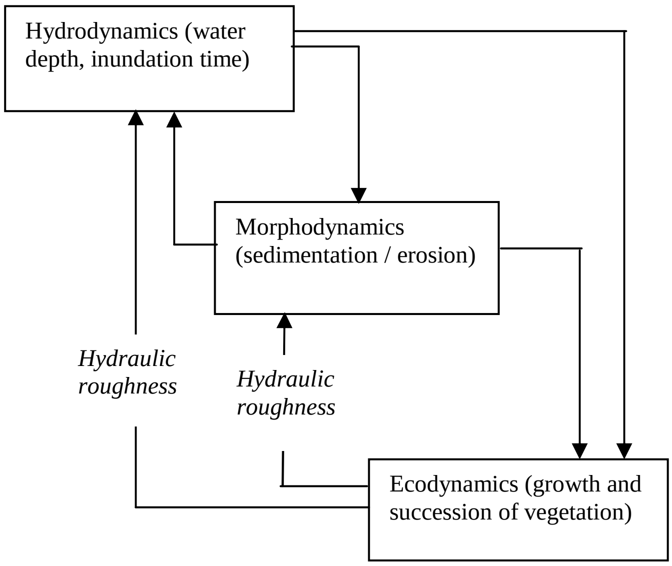
The study showed that the strategy of cyclic floodplain rejuvenation was able to sustain safe flood levels when about 15% of the total floodplain area was rejuvenated with a return period of 25 to 35 years. It also showed that these measures increased the diversity of floodplain habitats. One-dimensional analysis clearly demonstrated that the natural succession (landform and vegetation) in floodplains can diminish flood conveyance through a reach and that without frequent resetting mechanisms, the flood safety cannot be guaranteed. However, this study also stressed the need for better predictive modelling of the interactions between vegetation, flow and morphology, preferably in two- or three-dimensional models.

13.3 TWO-DIMENSIONAL MODELLING OF SECONDARY CHANNELS IN THE WAAL RIVER

The second case study deals with a complex of three man-made secondary channels that were created as part of a river rehabilitation project of the Rhine floodplains. The objective of this case study is to assess the morphodynamic behaviour of these secondary channels under different conditions of vegetation development on the channel banks (Baptist and Mosselman, 2002).

This study used the Delft-3D modelling suite applied in a two-dimensional morphodynamic mode, together with a rule-based vegetation model that describes the development of floodplain vegetation.
Figure 13.1 presents a schematic diagram of the model relationships applied in this case study. The effect of the vegetation on the transport of water and sand was modelled in the common way, as an increased bed roughness. The sediment transport formula applied assumed uniform sediment with a median grain size of 300 µm. The model described the morphological developments over a simulation period of 30 years. In one scenario the hydraulic roughness of the floodplain remained constant, whereas in the other scenario the hydraulic roughness changed due to vegetation growth and succession.

Figure 13.1 Relationships between the model components used in the Waal River Study



This case study showed that the medium-term morphological development of the secondary channels was affected by vegetation development. Generally speaking, there are remote and local effects of vegetation on morphology. The remote effects on the channel bed of the secondary channels were:- (i) near the entrance of the largest channel the bed eroded, as observed in reality, (ii) erosion was more pronounced in the runs with vegetation development, because then the increased roughness of the banks pushed the flow towards the channel axis. The mean erosion rate at the entrance was increased by 40% due to the development of vegetation. The remote effects of vegetation on the morphodynamics of the smaller channels showed that sedimentation increased by 25% to 70% due to the development of riparian vegetation. The magnitude of sedimentation agreed with final measurements. The local effects on floodplain levels, however, were erroneous. A couple of small islands that were present in the initial bed topography were washed away in the morphodynamic simulations. This local effect is a model flaw. In reality the vegetation stabilised the islands, but in the model the vegetation enhanced the transport of sediment. Furthermore, the simulations show a large eroding area downstream of a sand quarry. This resulted from the trapping of sediment in the deep pit. Moreover, the presence of vegetation enhanced the local transport capacity in the simulation, leading to an exaggerated erosion.

13.4 THREE-DIMENSIONAL MODELLING OF THE ALLIER RIVER, FRANCE

The third case study deals with a natural section in the River Allier. The objective of this study was to model the influence of vegetation on the flow velocities and morphology in this area. The Allier River is chosen as a reference river for the future Border Meuse in the Netherlands, after its rehabilitation.

A special version of Delft-3D, in a 3-D hydrodynamic mode was applied, with the vegetation modelled as rigid cylinders. A digital elevation model of the study area was acquired with the aid of RTK-dGPS and levelling. Aerial photographs of vegetation were analysed and vegetation types were mapped and subdivided in units that were characterised by cylinders with a certain diameter, height, density and drag coefficient. In this case study, results for flow velocity and bed shear stress were compared for the 3-D model and the 2-D model with enhanced bed roughness. In the latter case the vegetation units were also expressed in terms of a roughness height.

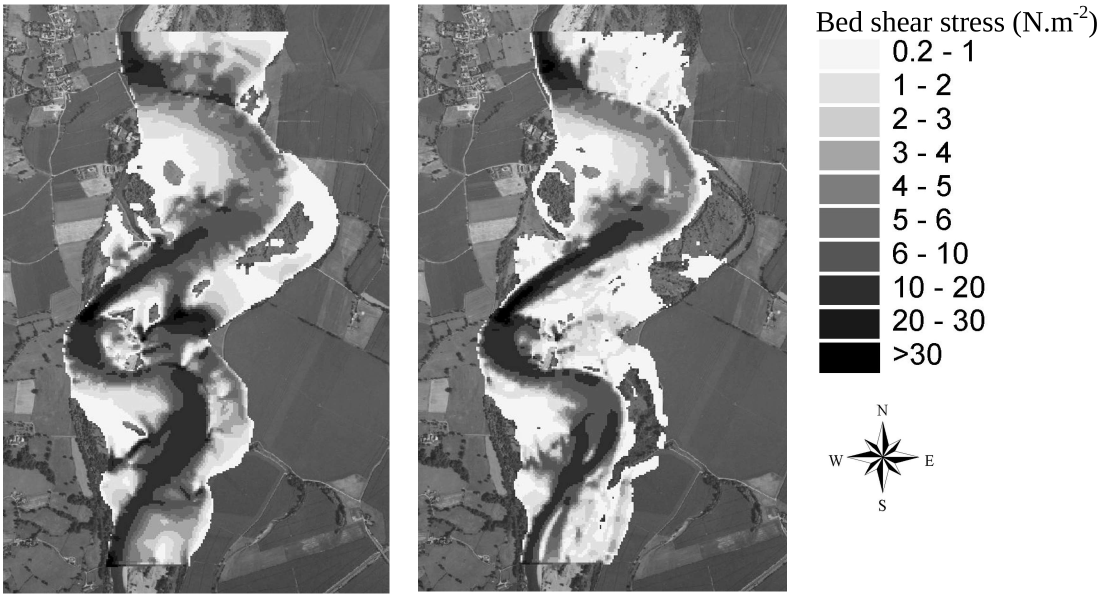


Figure 13.2. Computational results for the bed shear stress. Left panel: vegetation modelled as bed roughness, Right panel: vegetation modelled as rigid cylinders.

Results of this case study showed significant differences in bed shear stress patterns between the approach with vegetation cylinders and the approach with enhanced bed roughness (Figure 13.2). In the approach with enhanced bed roughness, the bed shear stress increased along with the bed roughness and showed very high values in places with dense vegetation. In the three-dimensional approach with vegetation cylinders, the bed shear stress was considerably reduced in places with dense vegetation. The distribution of bed shear stress was modelled more reliably, which is an important prerequisite for modelling the effects on morphodynamics.

13.5 DISCUSSION

The common approach to modelling vegetation roughness as enhanced bed roughness yields erroneous results in combination with common sediment transport equations as was shown in the second case study. A modelling approach has been developed in which vegetation is schematised as thin, vertical cylinders that slow down the flow due to the drag force on these cylinders. Furthermore, the presence of these vegetation cylinders affects the turbulent energy and dissipation of turbulence. The processes that are modelled in this way are more physically based than the approach using increased bed roughness. Since these processes are incorporated in a three-dimensional model, the flow and turbulence properties can be modelled over the vertical. The newly developed 3-D model is capable of describing more accurately the effects of vegetation on the bed shear stress as was shown in the third case study. This forms a basic ingredient for modelling sediment transport.

Modelling vegetation as rigid cylinders has been tested against data on flow and turbulence properties obtained in flume experiments. These results show that even for flexible vegetation reliable results are obtained. Results of a flume experiment on sediment transport with flexible, submerged vegetation show that indeed the sediment transport is reduced due to the reduced bed shear stress. On the other hand, the transport capacity for conditions with a relatively low bed shear stress is enhanced due to an increase in turbulence between the vegetation stems. It is recommended that continuous effort be put into experimental, field and modelling studies to understand the interactions of vegetation, flow and sediment transport at the level of principal processes.

Acknowledgements: Martin Baptist acknowledges the IRMA-SPONGE umbrella programme within the framework of the INTERREG-IIC initiative of the European Union and part of the Delft Cluster program within the Dutch ICES funding with project number 03.03.03. He also wishes to thank M.Sc. student Lara van den Bosch for her contribution to modelling the Allier River.

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