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Modelling dynamic roughness during floods

A.J. Paarlberg[1], **C.M. Dohmen-Janssen**[1], **S.J.M.H. Hulscher**[1], **A.P.P. Termes**[2]
[1] *Water Engineering & Management, University of Twente, P.O. Box 217, 7500 AE, The Netherlands;*
a.j.paarlberg@ctw.utwente.nl
[2] *HKV Consultants, P.O. Box 2120, 8203 AC, Lelystad.*

Abstract

In this paper, we present a dynamic roughness model to predict water levels during floods. Hysteresis effects of dune development are explicitly included. It is shown that differences between the new dynamic roughness model, and models where the roughness coefficient is calibrated, are most pronounced after the floodwaves.

Introduction

In the Netherlands, hydraulic models such as Sobek, are used to predict water levels. The main-channel roughness often acts as calibration coefficient in these models.
In the main-channel of rivers, dunes form on the sand-bed, especially during floods. Observations show a hysteresis effect between discharge and dune height (Fig. 1).

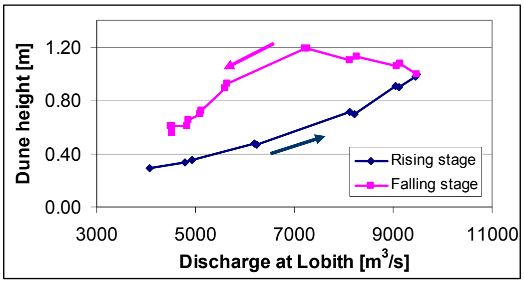

Figure 1: Hysteresis effect in dune height in the Upper Rhine during a flood (Wilbers, 2004)

In this paper, we present a model to predict water levels, which includes the hysteresis effect caused by dune development. This might result in better water level predictions over the entire range of floodwaves (rising stage, falling stage, and top/design discharge).

Roughness as garbage bin
The Chézy coefficient of the main-channel and floodplain are calibrated to match observed and computed water levels and discharge (distributions). All (model) errors end up in the roughness coefficient. In other words, the roughness coefficient acts as garbage bin of hydraulic models.
Figure 2 shows the calibration result for a relatively straight section of the Waal River, where the Chézy coefficients are a function of discharge, implying that hysteresis effects are not included in the model.

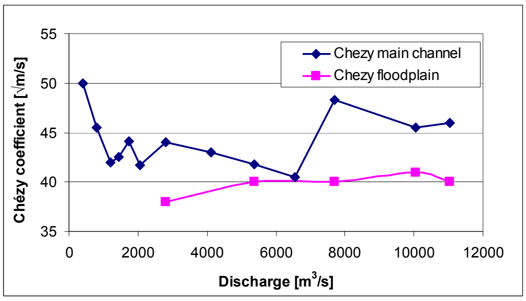

Figure 2: Calibrated Chézy coefficients of the main-channel and the floodplain as a function of discharge. (Waal rkm 885.23-900.88) (data from Udo et al, 2007).

Dynamic roughness model

We have developed a physics-based model to predict temporal dune evolution (Paarlberg et al., submitted). This model is now linked with Sobek to form the DrDude-model (**D**ynamic **r**oughness of **Du**ne **de**velopment). Figure 3 presents an overview of the model. Computed dune dimensions are translated into a roughness coefficient which is used in Sobek to compute the effects on water levels.

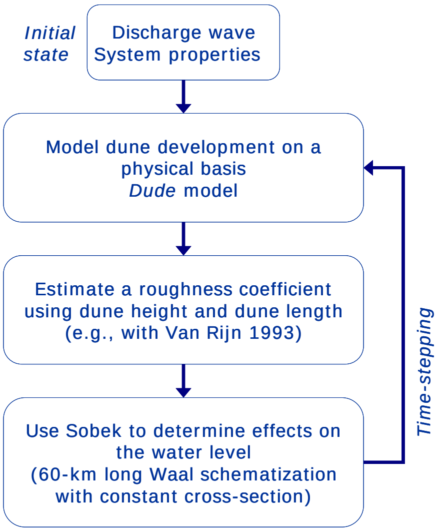

Figure 3: DrDude-model overview.

As Sobek model we use a simple 60-km long, straight channel with constant cross-section and channel slope, which is representative for the Waal River. In terms of Nikuradse roughness height, the roughness consists of:

$$k_{total} = k_{grain} + ck_{dunes} + k_{error}$$

where k_{grain} is grain roughness height, k_{dunes} is dune roughness height, and k_{error} represents the roughness height caused by (model) errors. k_{grain} is neglected with respect to k_{dunes}. The term 'k_{error}' is not known, and is therefore set to zero. The coefficient c = 0.35 is applied since dunes do not cover the complete river width and Van Rijn's relation was mainly based on flume tests.

Results

The DrDude model is used to simulate dune development and effects on water levels for two subsequent discharge waves (Fig. 4). There are periods of 1 week constant low discharge in between to initialize dune formation. At the start of the simulation the initial dune height is 5% of the average water depth in the main-channel. For the second discharge wave, the dune height is in equilibrium with flow conditions, at the start of the wave. Figure 5 shows a clear hysteresis in dune height, for both waves. The hysteresis in dune height also leads to hysteresis in roughness height since this is linked to dune dimensions (Van Rijn, 1993).
The effects on water levels are compared with the originally calibrated model in Figure 6. Differences occur especially after the floods, mainly because hydraulic models are calibrated on peak discharges.

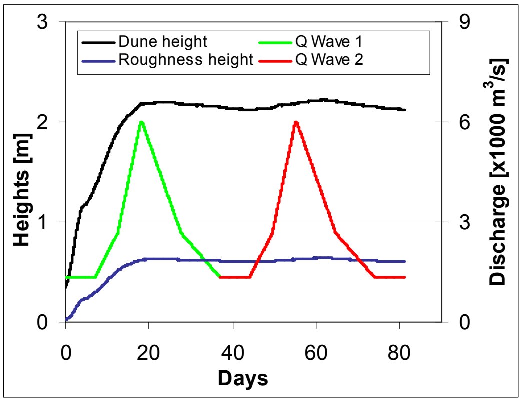

Figure 4: Two subsequent discharge waves with a sharp peak and periods of 1 week constant low discharge in between. Dune height and roughness height development over time are also shown.

Conclusions & Future work

Dune development, hysteresis in dune height and effects on water levels are successfully modelled with the DrDude-model. At the discharge peaks, there is not much difference in water levels, but in the falling and rising stage, there are some difference, especially after the waves. This modelling approach improves our physical understanding of the roughness coefficient of hydraulic models.

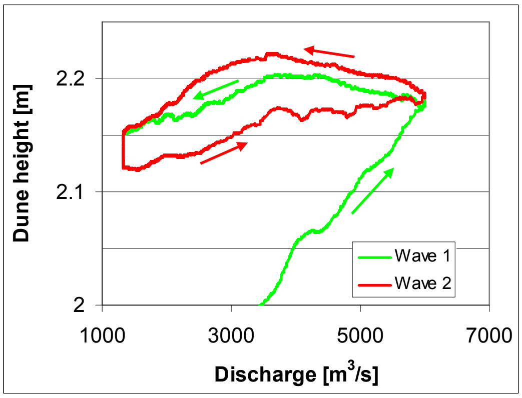

Figure 5: Hysteresis in dune height, for the two subsequent discharge waves. The arrows give the direction of development.

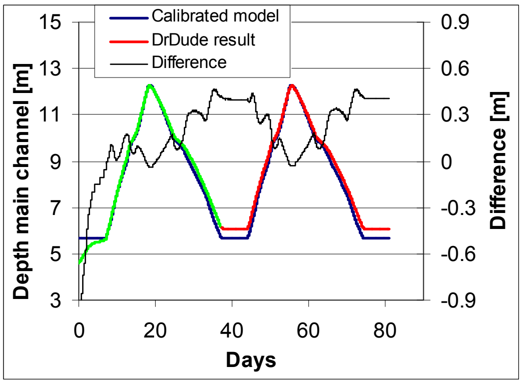

Figure 6: Comparison of DrDude model and the originally calibrated Sobek model.

Future work should aim on further increasing the knowlegde on elements in the garbage bin. Disentangling 'k_{error}' is necessary to find the next essential element in calibration. The model will be applied to other river sections (Upper Rhine) or other rivers (e.g., Meuse).

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