Upper stage plane bed in the Netherlands

R.J. Daggenvoorde*[1,2], J.J. Warmink[1], K. Vermeer[2], S.J.M.H. Hulscher[1]
[1] *University of Twente, Faculty of Engineering Technology, Group Water Engineering and Management, PO Box 217, Enschede The Netherlands*
[2] *HKV Consultants, PO Box 2120, 8203AC Lelystad, the Netherlands*
** Corresponding author; e-mail: r.daggenvoorde@student.utwente.nl*

Introduction

Upper stage plane bed (USPB) is a river bed form where no dunes or ripples are present on the river bed. The presence of USPB results in a lower roughness, which can lead to a reduction of 0.5 m in water level under design conditions (Van Duin, 2015). It is suspected that USPB might have been present in the Meuse near Heusden (Adriaanse, 1986), however it is still unknown whether USPB can develop under design discharge in the Netherlands. This study aims to find out whether and where USPB may occur under design conditions in the Netherlands.

Method

To find out whether USPB can occur in the Netherlands two analyses are performed. The first analysis uses flow and sediment characteristics to calculate Froude and Suspension numbers along the Dutch river system (Eq. 1 & 2).

$$Fr = \sqrt{\frac{u}{gh}} \tag{1}$$

$$Suspension\ number = \frac{u_*}{w_s} \tag{2}$$

Where; u is the flow velocity; g is the gravitational acceleration; h is the water depth; u_* is the shear velocity and w_s is the fall velocity. The flow characteristics are obtained from a WAQUA-simulation with a discharge of 16,000 m^3/s at Lobith. The sediment characteristics are obtained from measurements performed by RWS (Ten Brinke, 1997).

In order to determine the most probable location for USPB we introduce the USPB-index. This index is a dimensionless indicator which allows the comparison of different locations on their probability to develop USPB, however it does not represent a quantified chance on the occurrence of USPB. The USPB-index is computed as the shortest dimensional distance to the dashed line in Fig. 1. The indices are determined for every location in the Rhine branches and the Meuse with an interval of 20 meters. Values above the dashed in line in Fig. 1. are formulated as negative values, this allows to state that the location with the lowest USPB-index is the most-USPB-probable location.

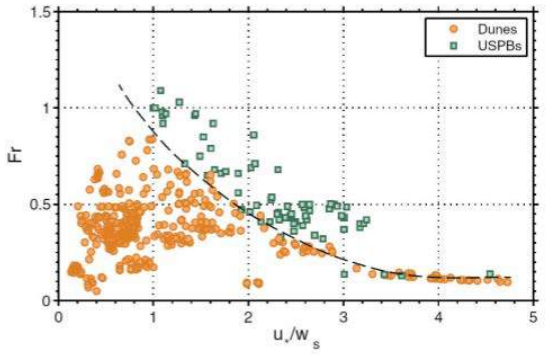

Figure 1. Observed bed forms with Froude and Suspension numbers (Naqshband et al., 2014a).

The second analysis incorporates the dynamic behaviour of dune development, using the morphodynamic model of Van Duin et al. (2017). Firstly, the model is calibrated upon observed equilibrium dune heights in flume conditions (Coleman et al., 2005; Naqshband et al., 2014b). Secondly, the model is calibrated upon river scale with observed dune heights in the Waal in 2002 and 2003 (Sieben, 2004). This second calibration is performed on the observed dune heights, by adapting the coefficients that influence the eddy viscosity and partial slip (beta-coefficients). Because there are no observations of USPB, the dashed line in Fig. 1 is used to calibrate the moment of the transition to USPB.

The re-calibrated model of Van Duin (2017) is then applied to the location with the lowest USPB-index. The design discharge wave of 16,000 m^3/s is used to create conditions which are most-likely to develop USPB.

Results

USPB-index

The IJssel just upstream of Kampen (river kilometre 994) was found to be the most probable location for USPB. The USPB-index was above zero (0.03), which means in the dune regime in Fig. 1, so it is expected that dunes will be present. Fig. 2 shows the USPB-indices along the IJssel mouth near Kampen.

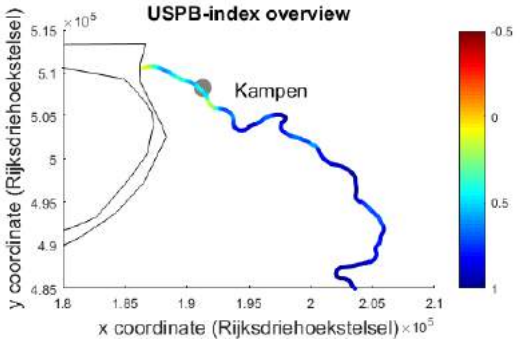

Figure 2. USPB-indices in the IJssel river near Kampen.

Results of the calibrations for field conditions

Adapting the step-length-model gave good results for flume conditions (Nash-Sutcliff=0.7) and adapting the beta-coefficients to 0.245 gave reasonable results for the calibration for field conditions (NS=0.3). The simulated water depths were in range with the observations. These results were considered sufficiently accurate to have confidence in the model to predict if USPB conditions can be achieved.

Upper Stage Plane Bed development under the design discharge

The fully calibrated model was applied for the IJssel near Kampen. The simulated dune heights during the design discharge wave show that USPB starts to develop during day 6 (Fig. 3). This suggests that USPB can develop in the IJssel just upstream of Kampen. The second most probable location (river Waal near Tiel) did not show development of USPB.

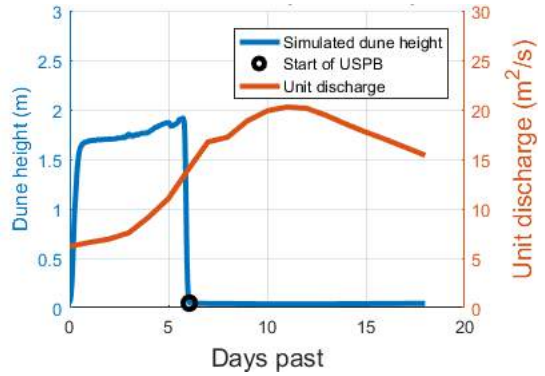

Figure 3. Dune height evolution during the design unit discharge wave at the IJssel near Kampen

Discussion

The model predicts USPB where the USPB-index does not. This difference may be caused by the model application on river scale and by the uncertain roughness in the WAQUA-simulation. The model on the river scale is applied on the middle of the river while the dashed line in Fig. 1 is based upon width-averaged observations. The width-averaged conditions required to develop USPB are higher than the conditions required in the middle of the river. The WAQUA-simulation uses the bed roughness to calibrate; this means the expected depth-discharge relation determines the bed roughness. Hence, the bed is simulated as dunes, while in the model of Van Duin (2015) the bed is dynamic allowing it to become a plane bed, resulting in other flow conditions.

The IJssel upstream of Kampen is the only assessed location found where USPB can develop according to the model and the most likely location according to the USPB-index. A detailed analysis showed that the small grain size at this location (D_{50} = 0.25 mm) is the main reason for USPB to develop. Therefore, USPB in the Dutch rivers is probably most likely when small grain sizes are present.

Conclusion

According to the model-analysis performed in this study the IJssel near Kampen may develop USPB under a design discharge wave. The dune evolution model of Van Duin et al. (2017) is applied upon a river scale and is shown to be able to predict dune heights and realistic hydrodynamic conditions. Also the exploratory analysis with the newly developed USPB-index indicated that this location is the most likely to develop USPB. Other locations scored higher on the USPB-index, indicating that USPB is less likely to develop, the dune evolution model showed that the second most probable location does not develop USPB.

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