NUMERICAL MODELLING OF SEDIMENT TRANSPORT OVER HYDRAULIC STRUCTURES

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Hydraulic structures are present in the designs of several Room for the River projects in the Netherlands. Examples are longitudinal weirs, groynes, summer dikes and weirs in the inlet of a side channel. Two-dimensional morphological simulations are frequently carried out to investigate the effect of such projects on for example hindrance for shipping and dredging costs. It is important that the physical processes around such hydraulic structures are correctly modelled in these situations.

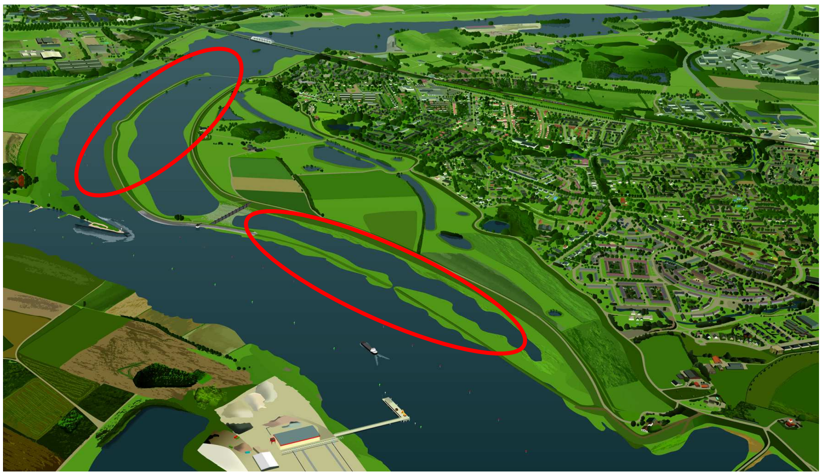

Figure 1 – Example of hydraulic structures in the Room for the River project "Hondsbroeksche Pleij"

Delft3D is often applied to perform two-dimensional morphological simulations of river projects. Delft3D is meant to model flow phenomena of which the horizontal length and time scales are significantly larger than the vertical scales. Near hydraulic structures, this is generally not the case. The structures are parameterised as weirs in a depth-averaged Delft3D model in engineering practice. The only effect of these weirs is an additional energy loss in the momentum equation. The parameterisation aims at representing the influence of the weirs on the flow at larger scales. The local flow characteristics around the structures are not correctly modelled. Moreover, there is no direct influence of the weir on sediment transport. This inaccurate way of modelling could result in errors in the prediction of the morphological effects of hydraulic structures. This problem leads to the objectives of this study:

Current way of Delft3D modelling	Assessing the performance of the current way of Delft3D modelling of sediment transport around hydraulic structures in three-dimensional flows.
Recommended sediment transport modelling	Making recommendations on the modelling of sediment transport around hydraulic structures in hydraulic engineering practice.

The performance of Delft3D has been judged by comparing the results with the results of the numerical model FLUENT. FLUENT is an advanced flow modelling system, in which sediment transport can be studied by analysing the trajectories of discrete particles. Firstly, some laboratory experiments describing flow and transport over structures have been modelled. In this way, the performance of both models has been investigated and mutually compared. The results of FLUENT gave confidence to use FLUENT as an instrument to judge the performance of Delft3D in modelling three-dimensional flow and transport over hydraulic structures.

A three-dimensional flow situation has been designed, which resembles the flow over a longitudinal weir. In Delft3D, all bed-load transport and suspended-load transport that reaches the weir also passes the weir. This results in continuous sedimentation patterns through the weir, as shown in figure 2. In FLUENT, this is not the case. Suspended-load transport is distributed between the main channel and the zone behind the weir in the same ratio as the discharge. The distribution of bed-load transport strongly depends on the particle diameter. This difference shows that the parameterisation of weirs in depth-averaged Delft3D models can result in significant errors in the prediction of sediment transport over hydraulic structures, especially when bed-load transport is dominant.

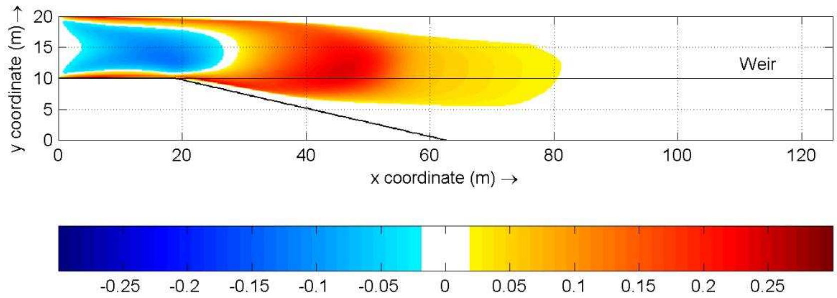

Figure 2 – Top view of sedimentation (red) and erosion (blue) [m] around a longitudinal weir

Because the structure is generally small with respect to the computational grid, the bed level of the surrounding grid cells is much lower than crest level of the weir. Increasing the bed level near the weir to crest level can reduce the transport magnitude. In this schematisation, nearly all bed-load transport is blocked and suspended-load transport is reduced. A weir without increased bed level overestimates the sediment transport over the structure. When the bed level is increased until crest level of the weir, the sediment transport over the weir is underestimated. The sediment transport over the weir can be tuned by an increased bed level somewhere between zero and crest level. This results in a need for a rule of thumb to estimate sediment transport around hydraulic structures.

The distribution of sediment between the main channel (index 1) and the area behind the weir (index 2) can be described with a bifurcation relation: $S_2 / S_1 = C \cdot Q_2 / Q_1$. The value of C as given by Delft3D can be judged with the following rules of thumb.

1. Suspended-load transport is distributed between the main channel and the zone behind the weir in the same ratio as the discharge, so $C = 1$.
2. For bed-load transport in three-dimensional situations with clearly oblique flow over the weir, the coefficient C can be related to the excess shear stress $S_\tau = \left(\theta - \theta_{cr}\right) / \theta_{cr}$ at the upstream slope, in which the actual Shields parameter θ and the critical Shields parameter θ_{cr} are adjusted for slope effects.
3. In situations where the flow is directed almost perpendicular to the crest of the structure, nearly all mobile sediment is transported over the structure in these situations.

The coefficient C in Delft3D can be influenced by giving the bed level near the weir the right height.