The effect of dike breaches on downstream discharge partitioning

Anouk Bomers[a*], Ralph M. J. Schielen[a,b], Suzanne J. M. H. Hulscher[a]
[a] *University of Twente, Department of Water Engineering and Management, Faculty of Engineering Technology, P.O. Box 217, 7500 AE, Enschede, the Netherlands*
[b] *Dutch Ministry of Infrastructure and Water Management-Rijkswaterstaat, P.O. Box 2232, 3500 GE, Utrecht, the Netherlands*

Keywords — Dike Breaches, Discharge Partitioning, Hydraulic Flood Modelling

Introduction

Flood frequency analyses (FFA) are widely used to estimate discharges associated with various recurrence times**.** The common procedure of a FFA is to select the annual extreme discharges of the measured data, which are then used to identify the parameters of a probability distribution. With this distribution, design discharges corresponding to any recurrence time can be computed.
However, a major drawback of the FFA is that the effects of overflow and dike breaches on the downstream discharge wave cannot be incorporated in the analysis unless such events have occurred during the measurement period.
Excluding overland flows from FFA results in an inaccurate prediction of design discharges since overland flows may alter downstream discharge partitioning. Water that left the river system may flow through the embanked areas towards another river or river branch, increasing the discharge of this specific river. The objective of this study is therefore to determine the effect of dike breaches on downstream discharge partitioning capturing the full dynamics of a river delta. The upstream part of the Rhine river delta is used as a case study.

Hydraulic model

A one dimensional-two dimensional (1D-2D) coupled hydraulic model is developed (Fig. 1) using the open source software HEC-RAS (Brunner, 2016) to simulate the discharges and flow velocities from Andernach (Germany) to the Dutch deltaic area. As upstream boundary condition a discharge wave is used whereas normal depths are used as downstream boundary conditions. The Manning's equation with a user entered energy slope (commonly equal to the slope of the river bed) produces a water level considered to be the normal depth.
The 1D profiles in the main channels and floodplains and the 2D grid cells in the embanked areas are coupled by a structure corresponding with the height of the dike that protects the embanked areas from flooding. If the computed water level of a 1D profile exceeds the dike crest, water starts to flow into the 2D grid cells resulting in inundations of the embanked areas.

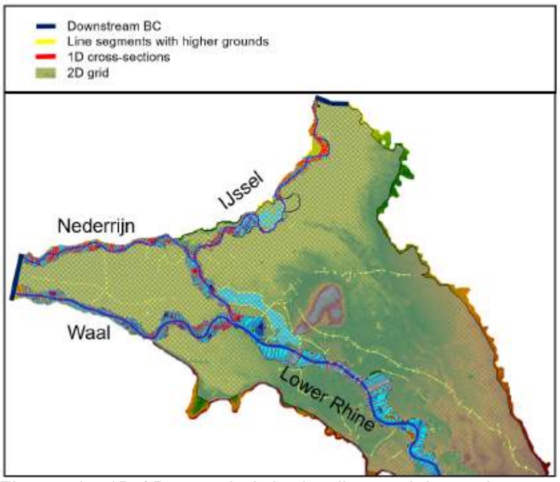

Figure 1. 1D-2D coupled hydraulic model used to perform the Monte Carlo analysis

Monte Carlo Analysis

A Monte Carlo analysis is performed to determine the effect of dike breaches on downstream discharge partitioning. In total 33 potential dike breach locations are included in the model that may change the downstream discharge partitioning as a result of large overland flows. The following input parameters are considered as random parameters in the Monte Carlo analysis:

- Upstream flood wave in terms of hydrograph shape and peak value
- Flood waves of the main tributaries (Sieg, Ruhr and Lippe rivers) dependent on the shape and peak value of the upstream flood wave
- Dike breach threshold in terms of critical water level (based on fragility curves) indicating when the

* Corresponding author
Email address: a.bomers@utwente.nl (Anouk Bomers)

dike starts to breach. Failure as a results of wave failure mechanisms wave overtopping, piping and macro-stability are considered (Diermanse et al., 2013).

- Dike breach formation time
- Final breach width

For each model run present in the Monte Carlo analysis, an upstream discharge wave and corresponding discharge waves of the three main tributaries are sampled. The 1D-2D coupled model computes the water levels along the river Rhine branches as a result of the upstream boundary condition and lateral inflows. If the simulated water level exceeds the dike crest, water starts to flow into the embanked area. Furthermore, the model evaluates at every time step and at each potential dike breach location whether the water level exceeds the dike breach threshold in terms of critical water level. If the critical water level is exceeded, the dike starts to breach based on the sampled dike breach formation time and final breach width. It is assumed that a dike breaches to the level of the natural terrain in case of failure (Daswon et al., 2005).

Results

During the Monte Carlo analysis, 375 runs were performed with a maximum discharge at Andernach ranging from 12,000 to 28,000 m^3/s.
In general terms, we found that dike breaches can significantly change the maximum discharges of downstream rivers. This effect is not only beneficial in terms of a reduction of the maximum discharge further downstream, as was found by Apel et al. (2009). Large overland flows may change the discharge partitioning of the Dutch river Rhine branches and hence the flood risk along these rivers.

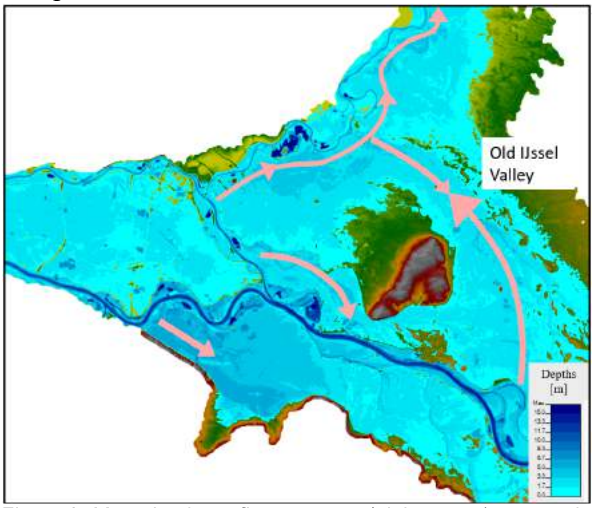

Figure 2. Most dominant flow patterns (pink arrows) present in the studied area. Specifically, the flow pattern through the Old IJssel Valley results in a change of the discharge partitioning of the Dutch river Rhine branches Waal, Pannerdensch Canal, Nederrijn and IJssel river.

Furthermore, a dike breach results in a sudden drop of the water level. This decrease of the water level propagates in upstream direction as a result of backwater effects. Consequently, the maximum discharge may increase upstream of the dike breach location.
For this specific case study, it was found that overflow and dike breaches along the Lower Rhine results in overland flows that consequently increase the maximum discharge at the downstream end of the IJssel river on average by 151% under the most extreme scenarios (Fig. 2: an example of potential flow pattern through the Old IJssel Valley). All other Rhine river branches were not affected by such overland flow patterns and hence only a reduction in maximum discharge as a result of upstream dike breaches was found for these branches.

Conclusions

We can conclude that dike breaches, resulting overland flow patterns and backwater effects must be included in the analysis of safety assessment since it may have a significant effect on downstream discharge partitioning and design discharges. This study shows that dike breaches may have a beneficial effect on some downstream river branches in terms of discharge reduction, while it may also cause severe problems along other river branches, especially if the discharge capacity of the specific river is relatively low compared to the discharge capacity of the other river branches.

References

Apel, H., Merz, B., Thieken, A. H. 2009. Influence of dike breaches on flood frequency estimation. Computers and Geosciences 35, 907-923.

Brunner, G. W. 2016. HEC-RAS, River Analysis system Hydraulic Reference Manual, Version 5.0. Technical Report. US Army Corps of Engineers, Hydrologic Engineering Center (HEC), Davis, USA.

Dawson, R., Hall, J., Sayers, P., Bates, p., Rosu, C. 2005. Sampling-based flood risk analysis for fluvial dike systems. Stochastic Environmental Research and Risk Assessment 19, 388-402.

Diermanse, F. L. M., De Bruijn, K. M., Beckers, J. V. L., Kramer, N. L. 2015. Importance campling for efficient modelling of hydraulic loads in the Rhine-Meuse delta. Stochastic Environmental Research and Risk Assessment 29, 637-652.