Propagating main channel roughness uncertainty in the bifurcating Dutch Rhine system

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Keywords — River bifurcation, Main channel roughness, Uncertainty analysis

Introduction

Bifurcating river systems around the world are complex and dynamically active systems. Natural processes and human interventions cause the system to change over time, which leads to variations in the discharge distribution over its branches. In the bifurcating river these changes cause changing water levels throughout the entire system.

The new Dutch flood risk framework requires the calculation of probabilities of water levels. Wherever possible uncertainties should be included in these probabilities. Generally, the upstream discharge and main channel roughness due to river bedforms are the dominant sources of uncertainty (Gensen, 2018; Warmink et al., 2013). This work aims to quantify the maximum effect of main channel roughness uncertainty on the range of possible water levels in the Dutch river Rhine system, including its two main bifurcation points.

Methods

Roughness scenarios

Roughness limit lines have been defined to represent the range of possible roughness values due to variations in bedform dimensions. For every branch (Waal, Pannerdensch Kanaal, Nederrijn/Lek and IJssel) a high and a low discharge-dependent limit line is estimated. These data points are based on available dune measurements and have been translated into roughness values using the roughness predictors of Van Rijn (1993) and Vanoni and Hwang (1967). The limit lines are then visually defined assuming a linear increase of the (Nikuradse) roughness with discharge. Figure 1 shows the roughness limit lines for the river Waal along with the roughness predictions. The combination of limit lines for every branch leads to 16 roughness scenarios, ranging from HHHH (high roughness on every branch) to LLLL (low roughness on every branch) in which the order is: Waal, Pannerdensch Kanaal, Nederrijn/Lek and IJssel.

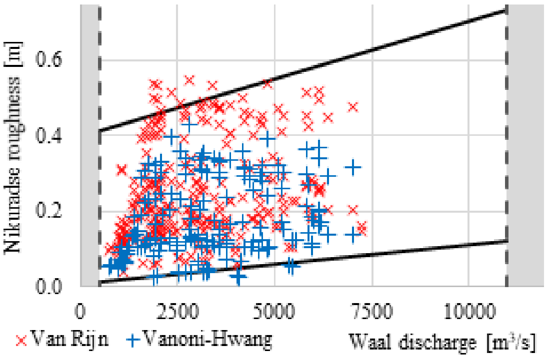

Figure 1: Roughness predictions in the river Waal. The black lines are the defined high and low discharge-dependent roughness scenarios.

Sobek model

An 1D Sobek-model of the Rhine Branches (Rijn-j16_5_v1) is applied to predict the water levels for each of the 16 roughness scenarios. The upstream boundary is a stationary discharge ranging from 1500 to 18,000 m^3/s.

Results

The effects of the varying roughness and the varying discharge distributions can be visualized in Qh-plots, in which the local water level is plotted versus Lobith (upstream) discharge (Figure 2). All scenarios in which the Waal has a large roughness result in an above-average water level. The spreading between these scenarios is caused by a changing discharge distribution at the Pannerdensche Kop. The highest and lowest water levels on the Waal are found for the scenarios in which all branches have a high and low roughness, respectively.

In Figure 3, the changes in local water levels are plotted against the changes in local discharges for all downstream branches (Nijmegen-haven for the Waal, De Steeg for the IJssel, Driel for the Nederrijn) for a Lobith discharge of 16,000 m^3/s. In this figure the roughness effect on the water level of the IJssel is indicated by Arrow 1, while the maximum discharge distribution effect for the IJssel is indicated by Arrows 2 and 3.

Figure 3 shows that the roughness effect is largest for the Waal and is smaller for the Nederrijn and IJssel. It is observed that for the

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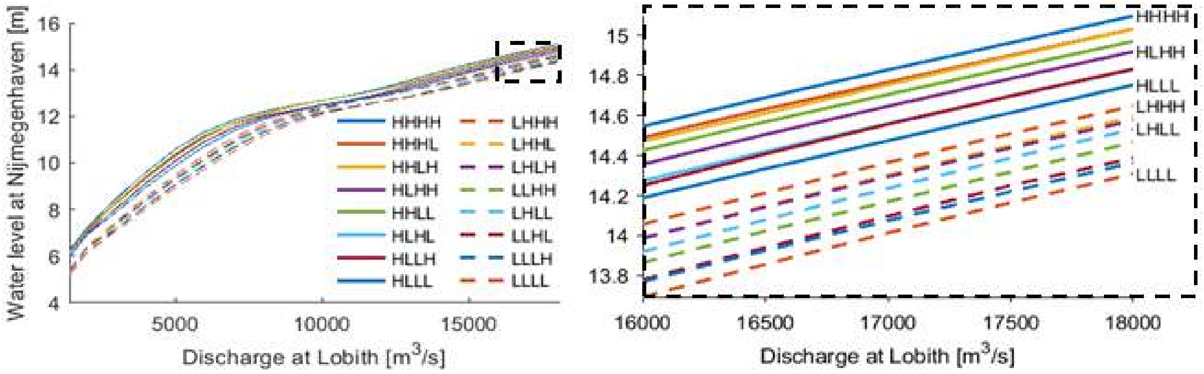

Figure 2: Stage at Nijmegen-haven plotted against upstream Lobith discharge for the 16 roughness scenarios. The right panel zooms in on the part of the stage-discharge relations at extreme discharges.

Waal the scenarios all plot in the upper left and lower right quadrant. This implies that for a high Waal roughness, the Waal discharge always decreases, regardless of the roughness on the other branches, thereby decreasing the water levels along the Waal. Scenarios exist for the Nederrijn and IJssel in which the discharge increases along with a simultaneous increase in local roughness (upper right quadrant). These scenarios generally correspond to scenarios with a high Waal roughness. Therefore, if the discharge distribution effect is included for these branches, the maximum water level increases. Concluding, the discharge distribution effect for the Waal thus causes a decreasing water level range, whereas the range increases for the IJssel and Nederrijn.

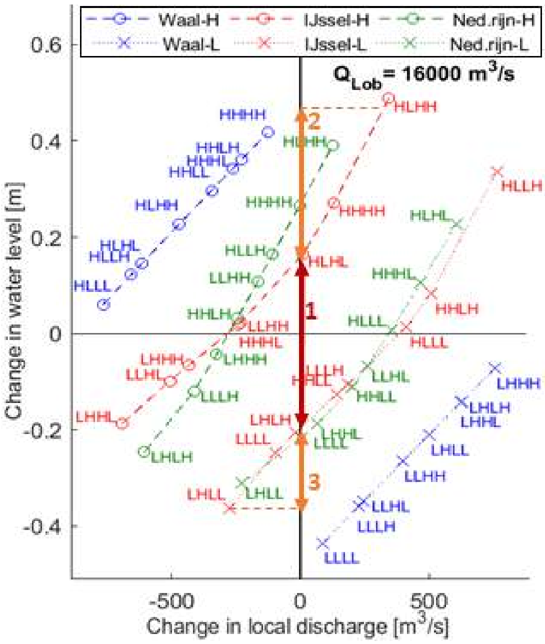

Figure 3: Local water level change versus local discharge change with respect to the average of all scenarios for a Lobith discharge of 16,000 m³/s.

Conclusion

By propagating extreme roughness scenarios through the 1D Sobek model an estimation of the maximum effect of uncertain main channel roughness on the water levels in the bifurcating river Rhine was attained. It is concluded that the effect of varying discharge distributions decreases the range of water levels along the Waal, while it increases the range for the Nederrijn and IJssel. In this study extreme roughness scenarios were applied. Therefore, the water levels should not be taken as absolute, but they show the trends in water levels under roughness uncertainty in a bifurcating river. In future work, more realistic scenarios are tested to quantify the water level ranges. Additionally, the effect of regulation structures and river engineering works in the vicinity of the bifurcation points on the propagation of the uncertainty to water levels will be analyzed.

Acknowledgements

This work is part of the Perspectief research programme All-Risk with project number P15-21, which is (partly) financed by the Applied and Engineering Sciences domain of The Netherlands Organisation for Scientific Research (NWO-TTW).

References

Gensen, M.R.A., 2018. Large-scale uncertainties in river water levels. Literature report. University of Twente, Enschede.

Van Rijn, L.C., 1993. Principles of sediment transport in rivers, estuaries and coastal areas. Aqua Publications, Blokzijl.

Vanoni, V.A., Hwang, L.S., 1967. Relation between bedforms and friction in streams. Journal of the Hydraulics Division, 121-144.

Warmink, J.J., Booij, M.J., Van der Klis, H., Hulscher, S.J.M.H., 2013. Quantification of uncertainty in design water levels due to uncertain bed form roughness in the Dutch river Waal. Hydrological Processes 27, 1646–1663.