CALIBRATING THE WAAL

DISCHARGE AND LOCATION DEPENDENCY OF CALIBRATED MAIN CHANNEL ROUGHNESS

Authors: Boyan Domhof, Koen Berends, Jord Warmink, Aukje Spruyt, Suzanne Hulscher

In the beginning of January 2018 the Dutch became invested in the upcoming high water in the Rhine and subsequently the Waal and other Rhine branches. People visited the banks of the River Waal to see the large amounts of flowing water for themselves. However, nothing catastrophic happened due to, for example, dike breaches or overtopping of the dikes. With the help of hydrodynamic models of the Dutch Rhine branches, the Dutch can accurately predict the water level everywhere along the river. However, to produce a sufficiently accurate hydrodynamic model you will need to calibrate and validate the model to water level observations.

INTRODUCTION

Calibration is the process of minimizing the error between model predictions and observations by altering the model parameters. Thus, in the calibration we try to adjust model in such a way that its predicted situation will be almost similar to the actual observed situation. Validation is performed after calibration. In this process we check whether the adjusted model also produces good model predictions in other situations than the situation used for calibration. In case of hydrodynamic models, the model is frequently calibrated using water level observations of a specific event, for example is extreme high water situation, and validated using another extreme high water situation or a low water situation.

In most calibration studies of hydrodynamic models, the hydraulic roughness coefficient parameter is altered in the calibrated because it is the most uncertain parameter (Pappenberger, 2005). This parameter is difficult to actually measure in the field without the need for large-scale and thus costly measuring operations. From previous studies, we know that both the physical and calibrated bed roughness can vary along the longitudinal direction of the river due to differences in bed sediment. Moreover, as discharge increases, river dunes grow in the main channel leading to an increasing bed roughness (Julien, 2002). Therefore, it is expected to the bed roughness is mostly dependent on the location along the longitudinal direction of the river and the discharge.

However, the study of Warmink (2007) points out that the calibrated roughness is not equal to the expected physical roughness because calibration also involves compensating for model errors or errors induced by the calibration method. Therefore, it remains unclear which features of the calibrated roughness are physically or model error driven.

The main objective in this study is to identify where and why differences between the expected physical roughness and the calibrated roughness occur. Validation is performed to check if capturing these differences in the calibration also result in more accurate water level predictions.

STUDY AREA: RIVER WAAL

As a case study object for this study we use the River Waal (as presented in Figure 2). The Waal is a distributary of the River Rhine in the Netherlands. Along the Waal, seven water level observation stations are operational of which station Dodewaard is only operational since 2001. The river is relatively straight and has an average bed slope of $1.1 \cdot 10^{-4}$ m/m. The main channel width is on average 260 m which doubles near the downstream boundary at Werkendam. The average discharge entering the Waal after the "Pannerdensche Kop" bifurcation is 1500 m^3/s. The river bed mainly consists of sand and river dune bed forms are present. In 1988 and 1999 artificial armoured bed layers at Nijmegen and Sint Andries were constructed to stall erosion of the outer bend. In 1996 submerged groynes at Erlecom were constructed to improve the navigability of ships. Large-scale interventions for flood risk reduction in the "Room

Title photo: Waal at Nijmegen during highwater beginning January 2018
Photography: Gemeente Nijmegen

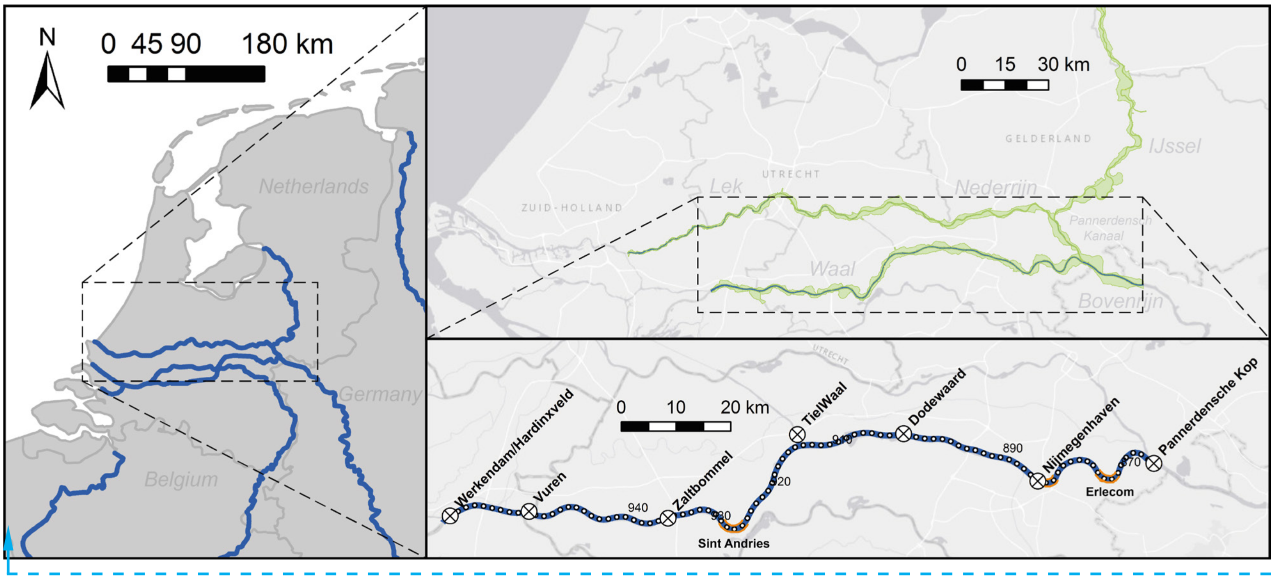


FIG. 2 Geographical overview of the River Waal in the Netherlands. Crossed circles indicate the location of water level observation stations. Orange highllighted areas indicate the location of submerged groynes or artificial armoured bed layers.

for the River"-project took place between 2007 and 2017.

METHOD

First, we calibrate the Manning coefficient of the main channel roughness of the 1D Waal SOBEK 3 model for the winter of 1995. We look at both the roughness in the longitudinal direction of the river (location dependent) and for different discharge stages (discharge dependent). The location dependency is investigated using a varying number of roughness trajectories for a bankfull discharge peak and a flood stage discharge peak. A roughness trajectory is defined as a river section between two water level observation stations with a uniform roughness. The discharge dependency is investigated using a varying number of discharge levels and five roughness trajectories. A discharge level is defined as the discharge for which the roughness is calibrated. Calibration is performed automatically using OpenDA.

Second, validation is performed using the calibrated roughness values with the 1D Waal models of the winters of 1993 and 2011 using a slightly adapted RMSE (Root Mean Squared Error) criterion. A lower RMSE means better water level predictions. Validation is performed on the whole three month time period of the discharge waves.

RESULTS: CALIBRATED ROUGHNESS

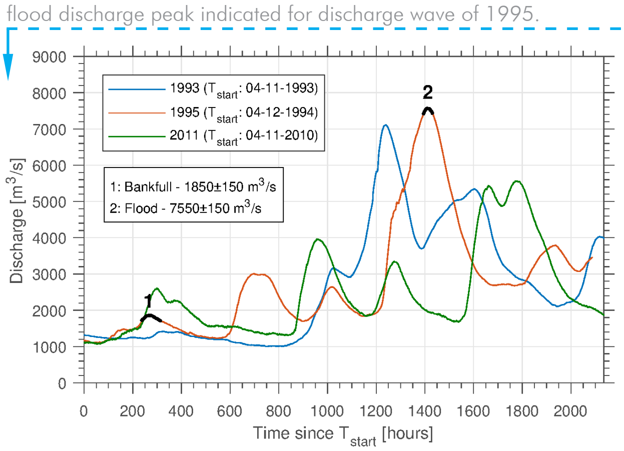
Calibrated roughness location dependency

Figure 4 presents the calibrated roughness for both bankfull and flood stage discharge peak for varying number of roughness trajectories. The roughness increase at river kilometre 882 is due to the artificial armoured bed layer at Nijmegen. The calibrated roughness is for both the bankfull and discharge peak overall fairly constant. Near the downstream boundary (starting from river kilometre 933) we see a difference in roughness occuring when increasing the number of roughness trajectories. This is possibly the result of an incorrect boundary condition propogating upstream through backwater effects up to observation point Vuren (at river kilometre 950). Calibration compensates for this by decreasing or increasing the roughness depending on the used discharge peak.

Calibrated roughness discharge dependency

Figure 5 presents the calibrated roughness-discharge functions for 2, 4, 6 and 8 discharge levels. Overall, the calibrated roughness increases as the discharge increases. However, more details appear if more discharge levels are calibrated. These details show at low discharge a sharp roughness increase, after which it decreases again and finally ends in a high roughness peak. The first roughness increase is expected as river dunes grow increasing the bed roughness in turn. The roughness decrease can be attributed to the transition from bankfull stage to flood stage. During this transition the hydraulic radius decreases suddenly.

FIG. 3 Discharge waves of the winters of 1993, 1995 and 2011 entering the Waal at the Pannerdensche Kop bifurcation. Bankfull and flood discharge peak indicated for discharge wave of 1995.



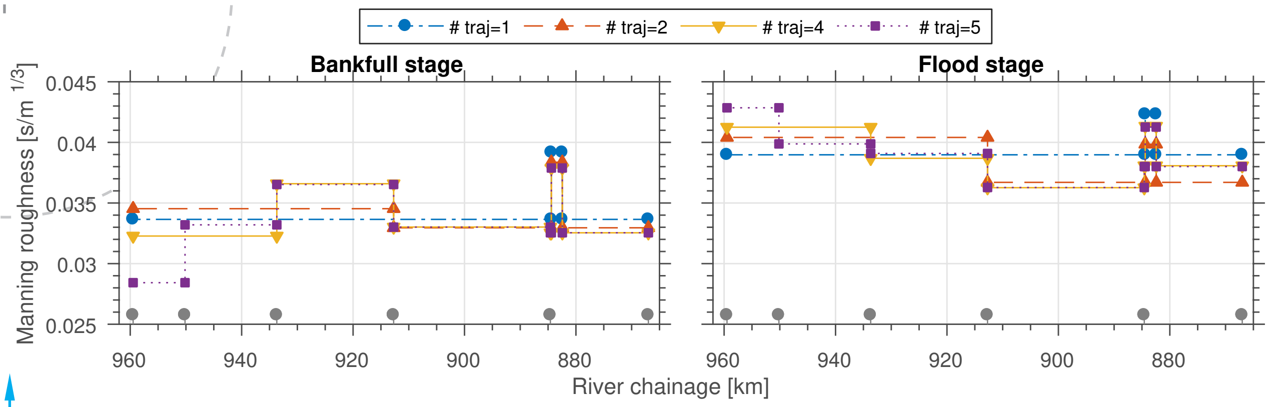


FIG. 4 Calibrated Manning roughness for varying number of roughness trajectories and for both bankfull and flood stage discharge peak. The grey dots right above the x-axis show observation station locations.

This leads to a lowered compound roughness (i.e. combined roughness of main channel and floodplain). However, this lowering is not enough and thus the calibrated main channel roughness must decrease to lower the compound roughness.

The roughness peak (around 6000 m³/s in Figure 5) is a result of the summer dike which is parameterized as a volume correction in 1D. In reality during the large discharge peak of 1995, openings in the summer dike were opened. This creates a discrepancy between the predictions and observations for which the calibrated roughness compensates.

RESULTS: VALIDATION

Location dependency validation

Figure 6a presents the validation results of the location dependent cases. The results of all three bankfull cases show a minimum RMSE (and thus the most accurate water level predictions) when using two roughness trajectories. However, for the three flood cases no minimum RMSE is present. Since we are both interested in low and high water situations and we have no clear minimum RMSE for both the bankfull and flood discharge peak, it remains inconclusive whether there actually exists one minimum for both situations.

Discharge dependency validation

Figure 6b presents the validation results of the discharge dependent cases. The RMSE of all instances are lower than the lowest RMSE in the location dependency cases (see Figure 6a). Making the main channel roughness dependent on the discharge with only two discharge levels already results in more accurate water level predictions than all location dependent cases. Therefore, it can be concluded that accuracy of water level predictions depends more on the number of discharge levels than on the number of roughness trajectories.

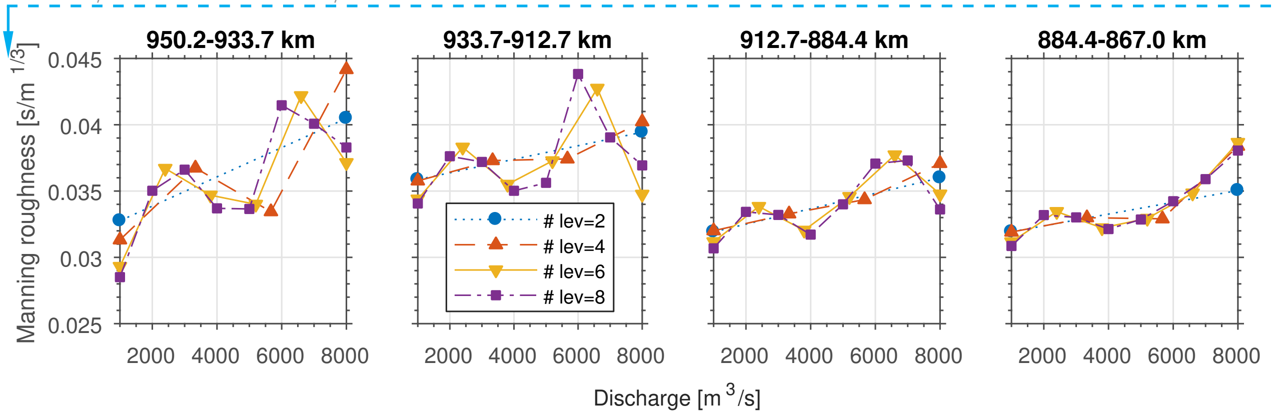
Both the 1993 and 2011 cases show a minimum RMSE value at six discharge levels. This corresponds to the calibrated roughness values where the transition from bankfull to flood stage and the effect of the summer dike are captured. However, improvement in RMSE between two and six discharge levels is minimal.

DISCUSSION

IJssel and newer Waal model

In this study we also calibrated a 1D model of the River IJssel for the winter of 1995 and a 1D model of the Waal for the winter of 2011. The resulting calibrated roughness values are similar to the ones presented in this article. However, the IJssel has sharp

FIG. 5 Calibrated Manning roughness-discharge functions for varying number of discharge levels. From right to left plots show the functions from upstream to downstream sections between measurement stations. The most downstream section is not shown, because results are largely affected by the downstream boundary condition.



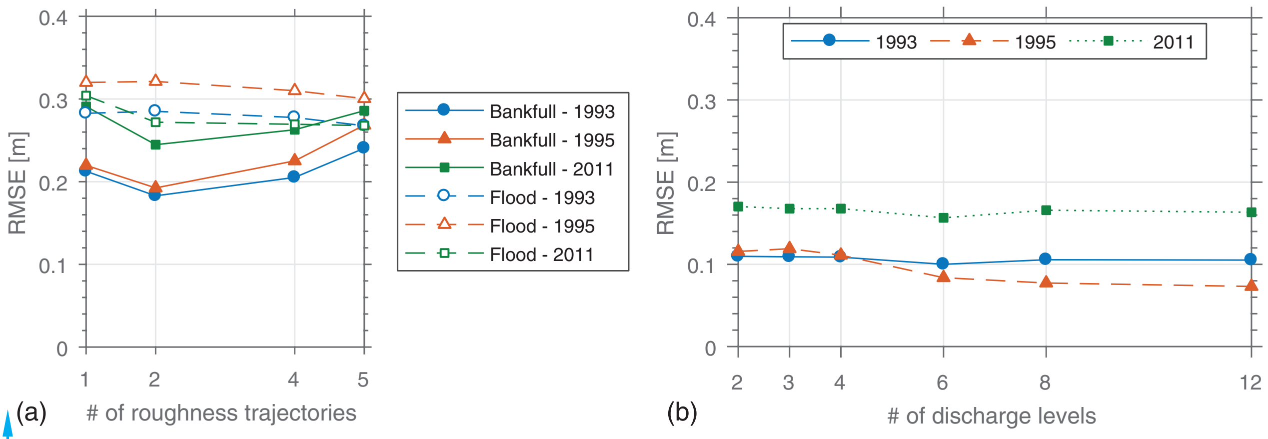


FIG. 6 a) Errors in water levels (RMSE), a) when calibrated on different number of roughness trajectories for bankfull discharge and flood discharge peak and b) when calibrated on different number of discharge levels

meandering river bends which are difficult to model accurately. Therefore, the calibrated main channel decreases with increasing discharge instead on roughness trajectories where these sharp river bends are present.

2D model

Furthermore, the presented results are based on an 1D model. However, not only 1D models are used for water level prediction but also 2D models. Therefore, we performed one calibration of a 2D model of the River Waal for the winter of 1995. The resulting calibrated roughness values lack the effect of the transition from bankfull to flood stage and the influence of the summer dike. Therefore, these functions more closely resemble the expected increasing roughness due to river dune growth.

CONCLUSION

The location and discharge dependency of the calibrated main channel roughness expressed by the Manning coefficient is studied using a case study on the River Waal in the Netherlands. The results show that the physical features of the bed roughness are present in the calibrated roughness values. In case of location dependency this can be seen in the fairly constant calibrated roughness along the whole river length. In case of discharge dependency this can be seen by an overall increase in roughness with increasing discharge. Differences in calibrated roughness and the expected physical roughness can be attributed to four reasons:

1. Incorrect downstream boundary condition;
2. Compound roughness method during transition from bankfull to flood stage is insufficient;
3. Influence of summer dike parameterization in 1D;
4. Sharp meandering river bends in case of the River IJssel.

The validation results show that incorporating these differences in the calibration will result in more accurate water level predictions for discharge dependent roughness. For location depdent roughness it remains inconclusive.

The validation results also show us that the calibrated main channel roughness is mostly discharge dependent as indicated by the lower RMSE values for the discharge dependent cases compared to all location dependent cases. This means that, if you calibrate a 1D hydrodynamic model of a lowland river like the River Waal by altering the main channel roughness, you should focus on the discharge and to a lesser extent on the location along the longitudinal direction of the river.

This study has been submitted as a conference paper for River Flow 2018. Contact the author for more information: boyan.domhof@gmail.com.

ACKNOWLEDGEMENTS

This study has been conducted at Deltares and University of Twente and is part of the RiverCare research programme, supported by the Dutch Technology Foundation TTW (project-number 13520), which is part of the Netherlands Organisation for Scientic Research (NWO), and which is partly funded by the Ministry of Economic Affairs under grant number P12-14 (Perspective Programme).

LITERATURE

Julien, P. Y., Klaassen, G. J., Ten Brinke, W. B. M., & Wilbers, A. W. E. (2002). Case Study: Bed Resistance of Rhine River during 1998 Flood. Journal of Hydraulic Engineering, 128(12), 1042–1050.

Pappenberger, F., Beven, K. J., Horritt, M. S., & Blazkova, S. (2005). Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations. Journal of Hydrology, 302(1–4), 46–69.

Warmink, J. J., Booij, M. J., van der Klis, H., & Hulscher, S. J. M. H. (2007). Uncertainty in water level predictions due to various calibrations. In CAIWA (pp. 1–18).