Abstract

Aim This thesis addresses the stochastic modelling of river morphology and the consequences for the navigability of a 37 km long stretch of the river Waal in The Netherlands. It should primarily give insight into the capabilities and limitations of one- and multi-dimensional models in predicting navigability, especially if a one-dimensional approach is sufficient or a multi-dimensional model has to be used to stochastically assess the navigability of a river.

Furthermore, it aims to give valuable advice for two groups of interest: (1) the river manager, who is interested in the navigability of the complete stretch, possible restrictions in space and time and the fulfillment of the minimum navigation requirements; (2) the modeller, who is interested in important sources of uncertainty for the navigability as well as an efficient setup of the simulations in terms of necessary number and time duration of the model runs.

Method The navigability of the river is assessed with the help of two morphodynamic models: a one-dimensional model based on the program SOBEK and a quasi-3D model based on the modelling package Delft3D. Both numerical models are used in a Monte Carlo Analysis (MCA) to take account of the uncertainty involved in the discharge, and compared to data of Least Measured Depth (LMD).

The principle of a MCA is to conduct a large number of model runs with statistically equivalent inputs. For each model run, a discharge time series of five years duration is statistically generated according to a prescribed probability distribution. On the basis of 100 simulations, the navigability is assessed in terms of the statistics of these model outputs.

Five characteristics of the navigability are defined: (1) the navigable percentage of time of the complete stretch; (2) the navigable percentage of time of each location along the river; (3) the navigable percentage of locations along the river as a function of time; (4) the percentage that a location forms the bottleneck location; (5) the probability that the navigation requirements are not given. Those characteristics are used in different approaches of analysis of the models and the data comparison to answer the questions of the river manager.

A method to estimate the number of required model runs to reach a certain accuracy of the model output as well as the behaviour of the uncertainty related to the number and duration of the simulations are presented to satisfy the needs of the modeller.

Results The 1D model leaves only one parameter to estimate navigability: the cross-sectionally averaged water depth. The quasi-3D model gives new possibilities as the navigability can be assessed in two dimensions, depth and width. An alternating behaviour of the channel in bends can be reproduced. Several additional morphologic phenomena like the evolution of a transverse bed slope in bends are included.

Both models show similar results in the prediction of the navigability for the first four of the five defined characteristics. The prediction of the restricting location per timestep, the "bottleneck location" differs. A correction for the transverse bed slope in bends shows to be essential and is successfully applied in the 1D model, in a parametric form. The comparison with the data of Least Measured Depth is not satisfying, due to several influences that are not included in the models (e.g. buoy placement and dredging). Furthermore, the criterion used is very sensitive.

For both models, the required number of simulations can be predicted very well beforehand. The effort for a MCA can thus be reduced. The uncertainty shows a strong dependency on the duration of the model runs. Higher uncertainties are found for short periods in order of one single year. This leads to the conclusion that a Monte Carlo Analysis is especially required for shorter model periods, as in this case the uncertainty related to the discharge is high. The discharge is found to have a large influence on the average navigability of the river, as well as on the resulting uncertainties.

Conclusions and recommendations The 1D model is applicable for a wide range of assessments of the navigability. For most of the assessed characteristics of navigability, the two-dimensional morphological effects that are not included seem to be of minor importance. The 1D model is able to predict the large-scale morphology (in the order of several kilometers) similar to the quasi-3D model. Furthermore, the range of uncertainty of the navigability estimated by both models shows a high agreement. The uncertainty included in the discharge time series seems to have a similar effect on both model outputs.

The quasi-3D model offers the opportunity to investigate the morphology and its effects on the navigability in two dimensions, including the corresponding morphologic effects as well as the shifting behaviour of the navigation channel in bends. This becomes important when locations that form restrictions for the navigation traffic should be identified. Even if the comparison with the LMD data is not completely satisfying, the results of this approach give the impression to be more trustworthy.

New data is necessary to validate the findings of the models. The available data of Least Measured Depth proves to be insufficient; it is not recommendable to identify one single location as being limitative to navigation. A new data set should be established: for a single stretch of the river, the water depth and the related channel width has to be measured and entered into a database for several permanent locations along the river on a daily basis.

The influence of the uncertainty in the discharge on the uncertainty of the navigability is large. Monte Carlo Analysis proves to be a possibility to assess these uncertainties. Nonetheless, the dependency of the uncertainty on the time duration shows that stochastic modelling is not always reasonable. For long modelling periods, a deterministic modelling approach still has its justification.

The same conclusion accounts for the model choice. A multi-dimensional model is not always necessary. For many of the relevant questions, a one-dimensional model can give sufficient insight with considerably lower effort.

Further research is necessary to assess the time dependency of the uncertainties and to investigate the influences of other uncertainties and their relative importance for different model durations. Finally, this kind of analysis should be applied to practical measures within the framework of the Dutch "Room for the River" program.

Keywords Navigation, Navigability, Morphology, Waal, Stochastic Modelling, Probabilistic, Monte Carlo Analysis, MCA, Uncertainty, Delft3D, SOBEK.