Assessment of climate change effects on navigable conditions on the river branches of the Rhine in The Netherlands.

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Title:
ASSESSMENT OF CLIMATE CHANGE EFFECTS ON NAVIGABLE CONDITIONS ON THE RIVER BRANCHES OF THE RHINE IN THE NETHERLANDS.

Abstract:
Inland Water Transport (IWT) is one of the modalities for freight transport between the ports of Rotterdam, Amsterdam, Antwerp and the hinterland in Germany. Transport over water between these areas is possible as a result of the presence of the Rhine, but more important are the navigation conditions on the river. As a result of climate change, these navigable conditions on the river will deteriorate in the future by lower extreme river discharges and sea level rise. The available navigable water depth will decrease on the Rhine branches Waal, Nederrijn en IJssel due to lower river discharges in dry periods, while the available head clearance under bridges becomes smaller for transport of containers in the Rhine-Meuse-delta. The worsening navigable conditions are amplified by long term-processes in the river system and trends in the freight transport sector. This will lead to the reduction of load capacity of vessels, an increase of travel time and travel costs. Stakeholders in the IWT-sector (port authorities, waterway authorities, shippers and barge operators) have the urgency to find out where potential bottlenecks may arise in the future and to develop mitigation measures. In the current literature numerical models are applied to assess the impact of climate change on Inland Water Transport for specific relations or processes. Simulations with those models is executed for one climate scenario or one time horizon for a larger part of the IWT –network. Other researchers make use of analytical relations applied on one or two bottlenecks for multiple climate scenarios and time horizons. An integral assessment to setup an overview of potential bottlenecks for multiple climate scenarios and time horizons based on an integrated model is lacking. In this project an integrated assessment meta-model is built to examine navigation conditions as a result of climate change and the impact on IWT. The focus of the first part of the project is to assess the climate change impacts on IWT. In the second part the aim is to develop and assess a number of mitigation measures. In this paper, first, an analysis of potential bottlenecks is executed. As a case study, the integrated assessment meta-model is applied on the river branches Waal and IJssel for one climate scenario and time horizon. The results give insight into the locations where problems will occur for navigation conditions and mitigation measures are needed to improve the conditions in case of low river discharges. The method and model will be applied for the assessment of mitigation measures in the second phase of the research project. The outcomes of the two research phases shall be used to define policies by waterway manager Rijkswaterstaat for efficient IWT in the future over the river Rhine or to develop new logistic concepts by ports, shipping companies or barge operators.

1 Introduction

Impact assessments of climate change on Inland Water Transport have been executed by several researchers. In these assessments all kind of models which varies from climate models to hydrodynamic models and logistic models are applied. Sometime the models are placed in a train of models which requires a lot of expertise of different fields to operate the model train. In this study a new type of model is built to assess the impact of climate change and effect of mitigation measures. The focus of the model is to improve the link between the hydrodynamic conditions of the river and inland navigation so it can be used to analyze the movement of vessels when the navigation conditions on the Rhine will become worse in the future and in case mitigation measures are applied.

2 Model setup

As stated in the previous paragraph we want to improve the interaction between the hydrodynamics and movement of vessels so the model consists of two main modules: 1) the hydrodynamic module and 2) the navigation module. The purpose of the first model is to examine the hydrodynamic conditions of the river system and whether bottlenecks will occur for inland navigation. The hydrodynamic conditions are the environment for the navigation module which will give depth restrictions to the vessels. A more detailed description of both modules is given in the following paragraphs.

Hydrodynamic module

The hydrodynamic conditions of the river system module are simulation runs with SOBEK-software. The input of the hydrodynamic module is the river discharge at Lobith which is determined based on the Dutch climate scenarios (Klein Tank et al., 2015; Sperna Weiland et al., 2015). In the module the schematization of the Rhine branches is applied to simulate the water levels in the system based on a 1D-approach. Combining the output of the water levels and the level of the bottom the available water depth in the cross-sections is determined. This provides the navigation conditions on the river stretches which are the properties of nodes and edges applied in the graph of the navigation module. Potential bottlenecks in the system can be determined based on the calculated available water depths.

Navigation module

For the navigation module the object oriented software Python is used and an agent-based modelling approach is applied. The agents represent the vessels and the environment is the hydrodynamic condition of the river system. Based on a graph which is built of the coordinates of the locations of SOBEK-schematisation of the Rhinebranches simulation-runs will be executed with a number of vessels which have to bring cargo from one location to another. Each vessel will be given a specific assignment (route and amount of cargo). Depending on the properties of the vessels and the environment the impact on inland navigation and vessels is simulated which is given by the number of trips and transport time.

3 Case study Rhinebranches Waal and IJssel

In the case study the model is applied on the Rhinebranches Waal and IJssel (see figure 1) in the Eastern part of the Netherlands. The case demonstrates how the model operates. The Rhine enters the Netherlands at Lobith and bifurcates in the Waal and the Pannerdensch Canal. Further downstream the Pannerdensch Canal splits into the Nederrijn and IJssel.

Figuur 1 Riverbranches of the Rhine, Leman (2007)

The Waal is the most important part of corridor Rotterdam – Germany, while the IJssel is a connection of the Rhine-East-Netherlands corridor. For this case study in the model vessels will bring cargo from Lobith to Werkendam which is located at the downstream end of the Waal and to lake IJssel. Figure 2 shows the schematisation of the system to simulate the hydrodynamic conditions. In this case study we apply the Wh,dry-scenario (Sperna Weiland, 2015) for the river discharges at Lobith for time horizon 2085.

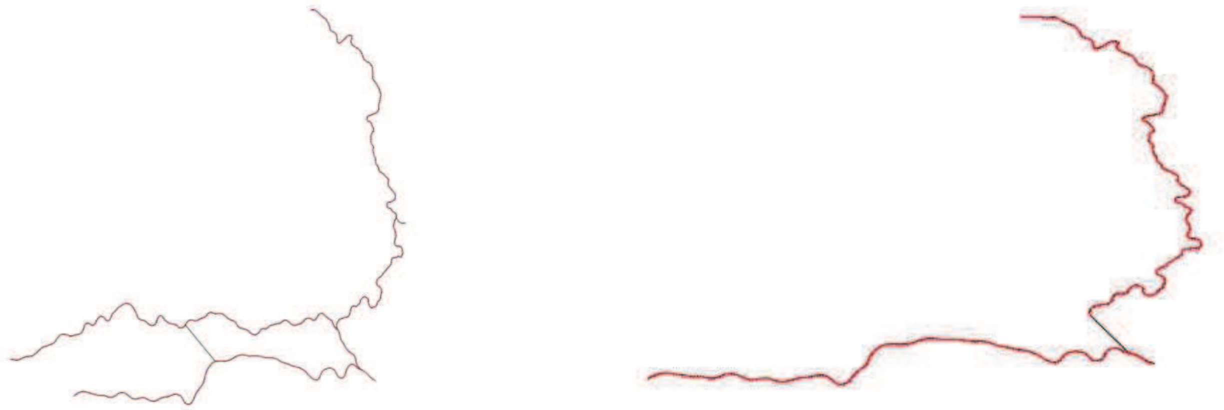
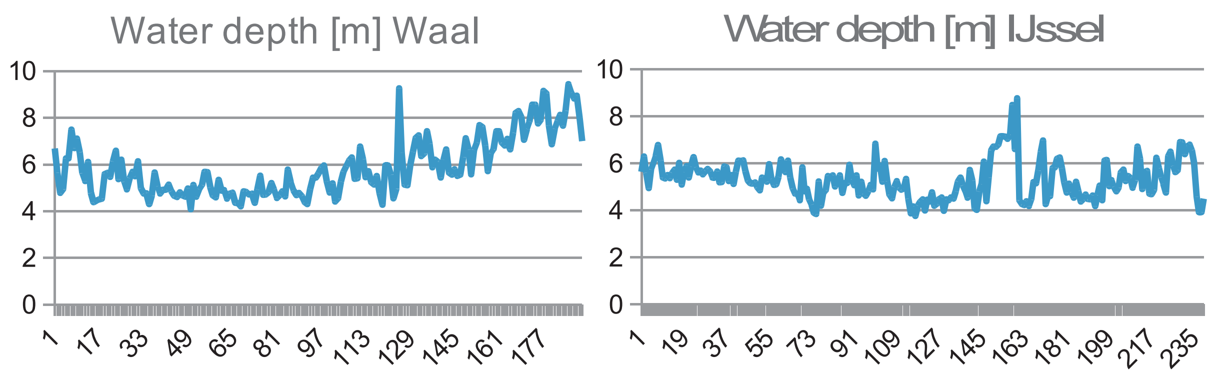


Figure 2 Schematisation of the Rhinebranches in SOBEK (left) and the schematisation of the Waal and IJssel in the navigation module (right).

In the navigation module we setup two paths which respresent the trips the vessels has to achieve and forms a graph (figure 2). For the navigation module we apply two vessels both with a capacity of 20.000 units. The vessel will bring cargo from Lobith to Werkendam which is the downstream location of the Waal and to lake IJssel at the downstreamside of the river IJssel. In the case study we assume 500.000 units has to be transported, 250.000 units to both destinations. For the case the brache Nederrijn is not taken into account, because this branche is canalized by three weirs with locks. The assumption is that this branche a sufficient water depth will be available.

4 Preliminary results

The SOBEK-simulation shows for the lowest river discharge in the $W_{h,dry}$-scenario which is 1000 m/s at Lobith on the river Waal and IJssel that for both branches the minimum waterdepth will occur on 16 resp. 15 september in 2085. In this case the minimum available water depth is 4.08 m and 3.76 m (see figure). For both branches the avaliable water depth decreased in comparison to normal conditions, but lead not to a large reduction of capacity of vessels. The $W_{h,dry}$-scenario is an avereged scenario which is eliminates the extreme low riverdischarges. We will apply more extreme scenarios in our further research to assess situations the navigable conditions will become more extreme.



Figuur 3 Water depths along the Waal (16-9-2085) and IJssel (15-9-2085)

In the navigation module we simulated how depth restrictions will influence the inland transport of cargo over the branches Waal en IJssel. In this case we assume different loading capacities of vessels which are 100%, 50% and 25%. The simulations (see figure 5) show an increase of both the number of trips (26 ,50, 100) and total transporttime (13 days, 20 days, 37 days) that is required to transport the amount of cargo from Lobith to the other locations at the downstream end of the Waal and IJssel. We also observe the difference in total time to transport 250.000 units from Lobith to the destination of the vessels. In our case vessel_2 navigated along a longer route and had a longer sailing time to complete the trip (see figure 4).

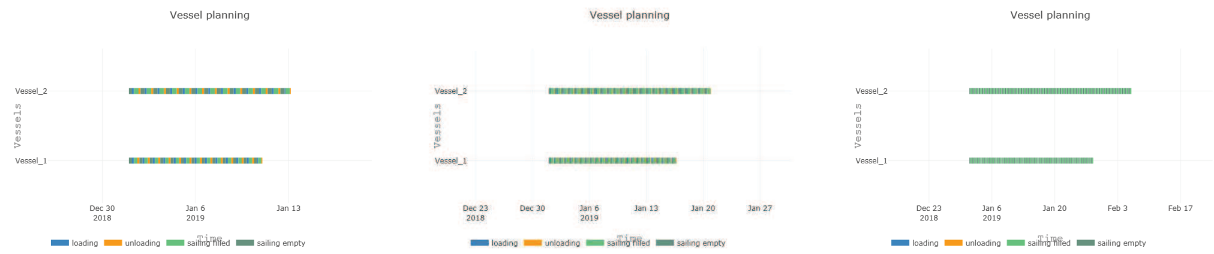


Figure 4 Transporttime with 100%, 50% and 25% filling capacity of the vessels

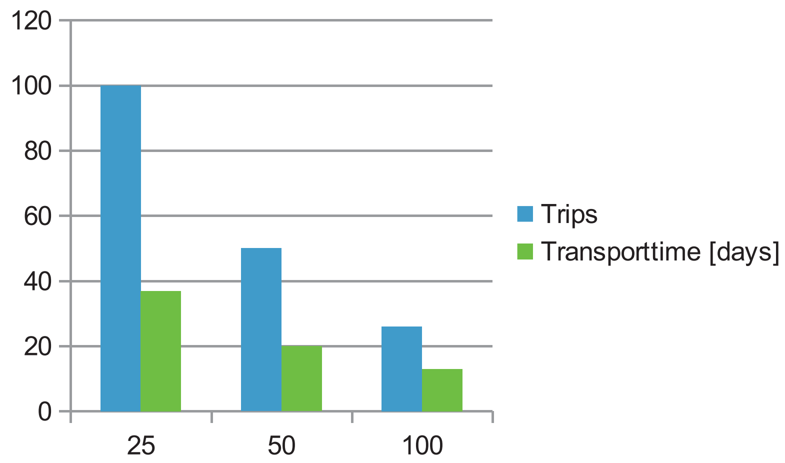


Figure 5 Number of trips and transporttime for 25%, 50% and 100% filling capacity of the vessels

5 Conclusions

In this paper a first version of the model which will be applied to execute impact assessments on inland navigation has been presented. The module consists of a hydrodynamic module which is based on SOBEK-simulations and a navigation module that is written in Python and applies an agent-based modelling approach. The assessement model was demonstrated for the case study of the Rhine branches Waal and IJssel in the Netherlands. Based on the results of the hydrodynamic module it can be concluded that in case of Wh,dry-secnario in 2085 the hydrodynamic conditions of the river might become worse around half of September at the Waal and IJssel. The navigation module shows an increase of trips and total time to transport a certain amount of cargo via the branches when the capacity of the vessels decrease as a result of the decreasing available water depth. In the case study we applied very simple approximations and assumptions of different variables, but we demonstrated the operation of the model. We will step by step improve the model which will lead to a more realistic model. The model will also be expanded such the model can be applied to examine the impact of climate change on inland navigation for the corridor Rotterdam – Germany and to analyze the effect of different mitigation measures.

Klein Tank, A. … Lenderink, G. (2015). Klimaatscenario's, 36. Retrieved from http://www.klimaatscenarios.nl/images/Brochure_KNMI14_NL.pdf

Sperna Weiland, F. … Beersma, J. (2015). *Implications of the KNMI'14 climate scenarios for the discharge of the Rhine and Meuse*.