Water level predictions using neural networks in critical gauges of the Rhine River, Germany

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ABSTRACT

Focus of this study is to investigate the capabilities of a neural network in predicting medium range water levels in some critical gauges of the Rhine Basin, being the river of greatest importance for inland navigation in Central Europe.

1 INTRODUCTION

Continuously changing climate and land uses, as well as human interventions such as water engineering practices and constructions, have a strong influence on the river hydrodynamics and its ecosystem [1]. Hence, rivers management needs to be adapted to its main water uses. In the last years, several researchers are exploring the use of data-driven models such as artificial neural networks (ANN) for hydrological applications, rather than hydrologic or hydrodynamic models (or in combination with them), to reduce running time and improve accuracy, regarding e.g. flood warning [2–4].

This study is focused on the Rhine River Basin. Besides its great importance for inland navigation in Germany, a significant growth in its traffic volume is expected in the upcoming years, according to the current Federal Transport Infrastructure Plan 2030 of the German Federal Ministry of Transport and Digital Infrastructure (BMVI). A more efficient use of the existing waterways is thus required, as well as new approaches to avoid or reduce undesired congestions on rivers and canals. In this context, the study conducted contributes to the BMVI-funded project Digital Skipper Assistant (DSA), whose main purpose is to explore the feasibility of an optimized water level prediction model, able to determine routes and load limits in a fast and efficient way for the German waterways.

In the framework of the DSA project, the ongoing work presented here intends to investigate the capabilities of an artificial neural network, designed for water level predictions in some critical gauges of the Upper and Middle Rhine (Southwest Germany) as alternative or complement to the existing physically based model chain. The basic idea consists of the determination of a downstream water level based on one or more measured upstream levels, characterized by a certain flow time lag, and possibly other variables (e.g. precipitation or hydrological model output).

The data set used to prepare the training data consists of long-term data series of hourly measured water levels, covering a period of about 27 years i.e. between 11/1/1988 and 4/1/2016 (the first 80% of the series i.e. 11/1/1988-10/10/2010 was used for training and the last 20% i.e. 10/11/2010 and 4/1/2016 for validation). The first target gauge is in Oestrich (at Rhine-km 518.1), while the levels used as inputs for the network are the ones registered in Maxau (at Rhine-km 363.3), the first free-flowing gauge of the Upper Rhine, and other two along the tributaries Neckar and Main, respectively Rockenau and Frankfurt, located next to Raunheim (Fig.1). The estimated time lags in hours between the different gauges are reported in Tab.1.

Table 1. Flow time lags (in hours) estimated at the gauges

	Maxau	Rockenau	Frankfurt	Oestrich
Maxau	0	20	36	36
Rockenau	20	0	24	24
Frankfurt	36	24	0	4
Oestrich	36	24	4	0

According to the main concepts of the ANNs for hydrological applications [5], different sensitivity analyses will be conducted in order to find the optimal network's design for this specific application. The principal research question turns around whether it is possible to gather a reliable and fast forecast for a certain stretch or for the entire Rhine River using ANNs and for which lead-time (short or medium range).

First exploratory tests are being conducted using a logistic sigmoid as activation function and a feed-forward back-propagation as learning method (FFBP). E.g., for a 1 day-water level prediction, the data observed and the ANN results for the gauge Oestrich showed good accordance (the determination coefficient R^2 is equal to 0.98), with a computational cost for training of few minutes. Figure 2 shows first validation results, comparing the expected with the predicted water levels.

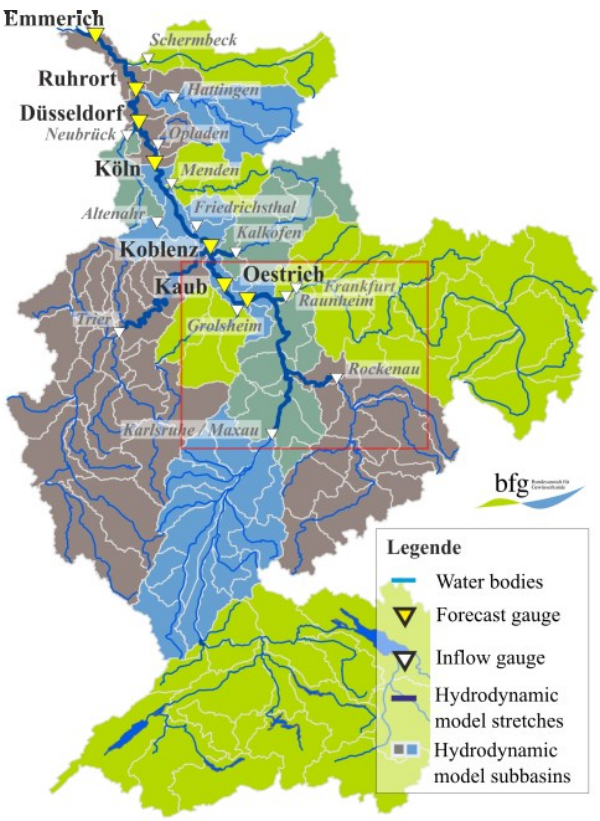

Figure 1. Catchment area of the Rhine up to gauge Emmerich, at the border with the Netherlands, linking the hydrological and hydrodynamic model components of the traffic-related prediction system of the Federal Institute of Hydrology (BfG) for the Rhine waterways. The red frame highlights the starting gauges.

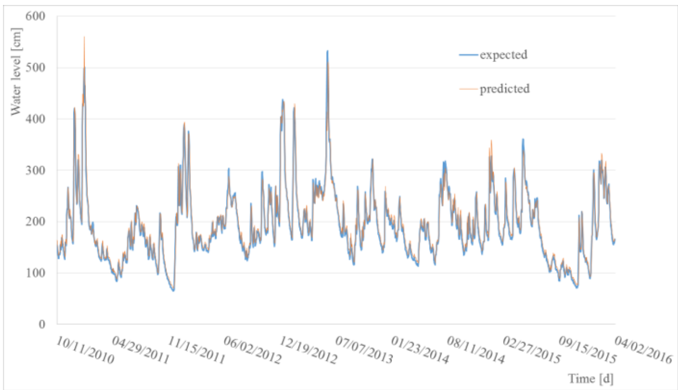

Figure 2. First validation results (20% of the data series, i.e. 10/11/2010-4/1/2016) of a trained FFBP-ANN, showing the expected (measured) water levels and the 1-day water level predictions for the same gauge in Oestrich.

The next steps concern further developments of the network, where the downstream target gauge station will be always constructed on the data basis of the previous upstream water levels on the Rhine or of significant tributaries. Moreover, the influence of further variables such as the precipitation or date of the year on the accuracy of the results will be investigated. Further, recurrent neural networks (RNN) such as the Long Short Term Memory (LSTM) may be investigated as an alternative option to the FFBP, being capable of learning long-term dependencies and, therefore, enabling predictions for a longer period.

Such research applications and experimental developments are highly needed by federal and state governments, as well as by water and shipping administrative authorities, because they contribute to design high-performance demand-oriented tools for the direct promotion of the environmental and transport policy goals in the inland waterways.

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