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A rule-based modelling concept to simulate hydromorphological measures – a tool for the design of programmes of measures for the EU Water Framework Directive

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Abstract. Hydromorphological deficits are of real concern regarding the goals of the European Water Framework Directive to reach a good ecological status. The effects of measures that change the morphological structure of a river is hard to predict. Existing methods to simulate this process in a traditional numerical model can not be applied to whole river systems. Using a rule-based modelling concept to find feasible measures and predict the impact of those measures is a very promising solution.

1 Introduction

In the past the focus of programmes of measures has been on the water quality. With respect to this objective the achievements have been very impressive. Still there are considerable deficits in the morphological structure particularly in urban areas. Those deficits result for the most part from former river regulation measures. The situation of morphological deficits is in Germany nationwide similar. To give some impression the circumstances in North Rhine-Westphalia (NRW) are presented: 48.6% of the small and medium sized water bodies are classified as 6 or 7 out of 7 classes (whereas class 1 represents a natural state and class 7 a completely unnatural state). In urban areas this percentage even increases to 73.6% (LUA NRW, 2003).

Classical measures to improve the morphological structures are normally expensive and time-consuming. To avoid large and expensive renaturation projects, measures that support the dynamic development of the rivers are preferred within the future programmes of measures of the EU Water Framework Directive (EU WFD). Crisp mathematical modelling of such measures and the prediction of their impacts are very laborious and as complicated as challenging. Nonetheless we need to assess programmes of measures that will take us to the objectives of the EU WFD. Rule-based modelling of hydromorphological structure is one targeted way to solve the existing problems (Nacken and Sewilam, 2004).

There are quite a lot of existing models and decision support systems for the implementation of the EU WFD at present (e.g. Dietrich, 2006; Möltgen, 2005; Watkins, 1995; Hostmann, 2005). Still a tool that integrates the selection of suitable morphological measures and the prediction of their effects on the morphological structures to identify potential programmes of hydromorphological measures is not yet available.

2 Morphological quality assessment of water bodies

A morphological quality assessment in North Rhine-Westphalia surveyed all significant small and medium-sized water bodies on a level of 100-meter segments. The method of mapping used is described in LUA NRW, 1998. The core parameters to describe the morphological quality are a group of 14 functional entities, that are none crisp but descriptive values. Table 1 shows the total number of parameters used in this method. The assessment classifies the parameters into seven classes, where class 1 represents a natural state and class 7 a completely unnatural situation. The results of the 14 functional entities can then be aggregated to 6 main parameters and to a total value for the whole segment.

As the parameters are all descriptive they suit perfect to the method of rule-based modelling. Within this method computations are done on a basis of expert knowledge encoded in a set of interdisciplinary rules.

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Table 1. Functional entities and main parameters of the morphological quality assessment (LUA NRW, 1998, translation done by author).

Functional entity	main parameter
curvature movability	development of the longitudinal section
natural longitudinal section elements anthropogenic migration barrier	longitudinal profile
type and variety of the substrates bed stabilization	bed structure
cross profile shape cross profile depth variety of channel width	cross profile
natural plant cover on bank bank stabilization natural bank characteristic	bank structure
foreland bank strip	stream surroundings

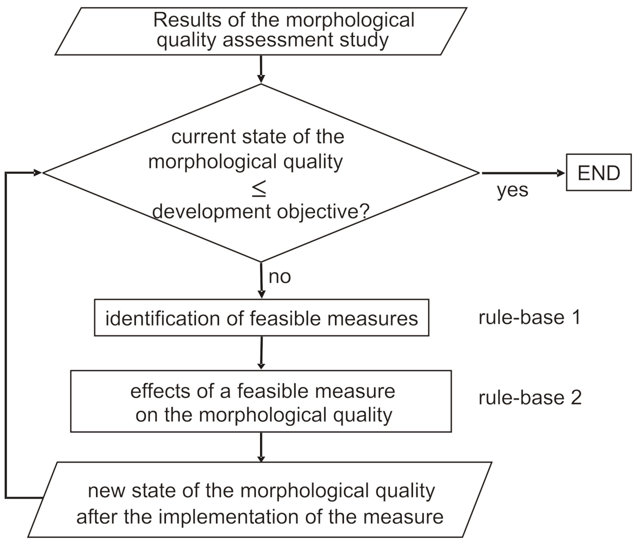

Fig. 1. Scheme of the modelling tool.

3 The rule-based modelling concept

The rule-based modelling tool (called DSS-WRRL) can answer questions such as "What combination of measures will be best to reach the morphological goal of the EU WFD for a certain water body". It takes into account all existing restrictions while searching for the best combination of measures. The modelling tool delivers and evaluates statements on the effects of feasible measures and combinations of those measures. This calculation is done in two consecutive stages. Figure 1 shows the scheme of the modelling tool.

First the user has to choose the river segments that the modelling tool shall calculate. Furthermore the development objective has to be specified. The actual results of the morphological quality assessment are loaded from the database. If the development objective is not yet reached, the modelling tool will suggest several combinations of measures to reduce these deficits. To do so, the system will first identify several feasible measures to improve the current state. This part is done by rule-base 1 (Identification of feasible measures). Within rule-base 1 the rules of experts that are stored in IF-THEN rules within a dataset are applied to the actual state of the river segment. Table 2 is giving an example of such a rule for the application of a deadwood measure.

Once the model has found a feasible measure to reduce the existing deficits it will simulate the affects of the measure after a certain duration (called duration of impact). The model will predict the morphological quality of the river segment that will be reached after applying the measure. Therewith the model has produced a new morphological state and has to evaluate whether the development objective has already been reached. Table 3 is showing an example of this stage of process simulation.

If the predicted state of the morphological quality after the implementation of the measure reaches the development objective or even a better state, then no further measures are proposed. Otherwise, a second measure is suggested and the effects of the combination of both measures are calculated. At the end, all combinations of measures which reach the given development objective in the given development time are displayed.

Table 2. Example of Rule-base 1: Identification of feasible measures.

	parameter	characteristic
IF	curvature	= mostly straightened
OR	curvature	= totally straightened
AND	natural longitudinal section elements	= rare
OR	natural longitudinal section elements	= very rare
AND	bank strip	= adequate
AND	bed stabilization	= without lining
AND	bank stabilization	= without bank protection
THEN	deadwood	= feasible

Table 3. Example of Rule-base 2: process simulation.

	parameter	characteristic
IF	curvature	= totally straightened
AND	natural longitudinal section elements	= rare
AND	measure	= one-sided deadwood
AND	river width	= moderate
AND	river depth	= 20–100 cm
AND	duration of impact	= 5 years
THEN	curvature	= mostly natural curvature
AND	movability	= mostly natural movability
AND	natural longitudinal section elements	= frequent natural elements

Examples for single measures included in the DSS-WRRL are as follows: removal of bed stabilization, removal of bank stabilization, inserting of natural substrates, inserting of deadwood, stimulation of natural plant cover, cross section widening.

All solutions that are calculated by the model can be assessed in respect of effectiveness and/or related costs. The system determines the costs of each measure for each river segment. This is done fairly precise by using additional data of the morphological quality assessment. Information on the river width and depth, on existence and type of bed and bank stabilization and about the location (urban or rural) et cetera is included into the calculation. The costs are internally calculated in Euros. The user however gets only normalised values. This estimation of costs shall not serve for an accurate prediction of the real costs, but for the assessment of the financial tendencies and differences between the possible programmes of measures. The cost-effectiveness is calculated as a division of the estimated costs and the reached improvement of the morphological quality.

The rules have been jointly set up by a group of experts from the water authorities and water associations, who are dealing with projects to improve the morphological structures of the water bodies.

4 Results

The tool in his first version is accomplished. The training course for the responsible water authorities, the future users of the system, is planned and will be the kick-off for the use of the tool in the water administration of North Rhine-Westphalia.

At present only few data is available for the validation of the system. This data does not cover all measures and all conditions that are implemented in the tool. The validation results for the available data showed good and promising results, although the different and sometimes special conditions of the sites and inaccuracy of the survey data have to be taken into consideration. As soon as new data from monitoring projects will be available the parameterisation of the system will be adapted and even more improved.

The system has been tested during the phase of deployment on different river systems (Berkel, Issel, Niers, Rur, Stever, Sieg, Ottersgraben and Wienbach) in North Rhine-Westphalia. The results are as well very instructive as very promising and show that rule-based modelling can supply traceable and resilient programmes of measures for rivers systems of all scales.

In Fig. 2 a small section of a map shows the outcome of a model run. The map presents the morphological quality

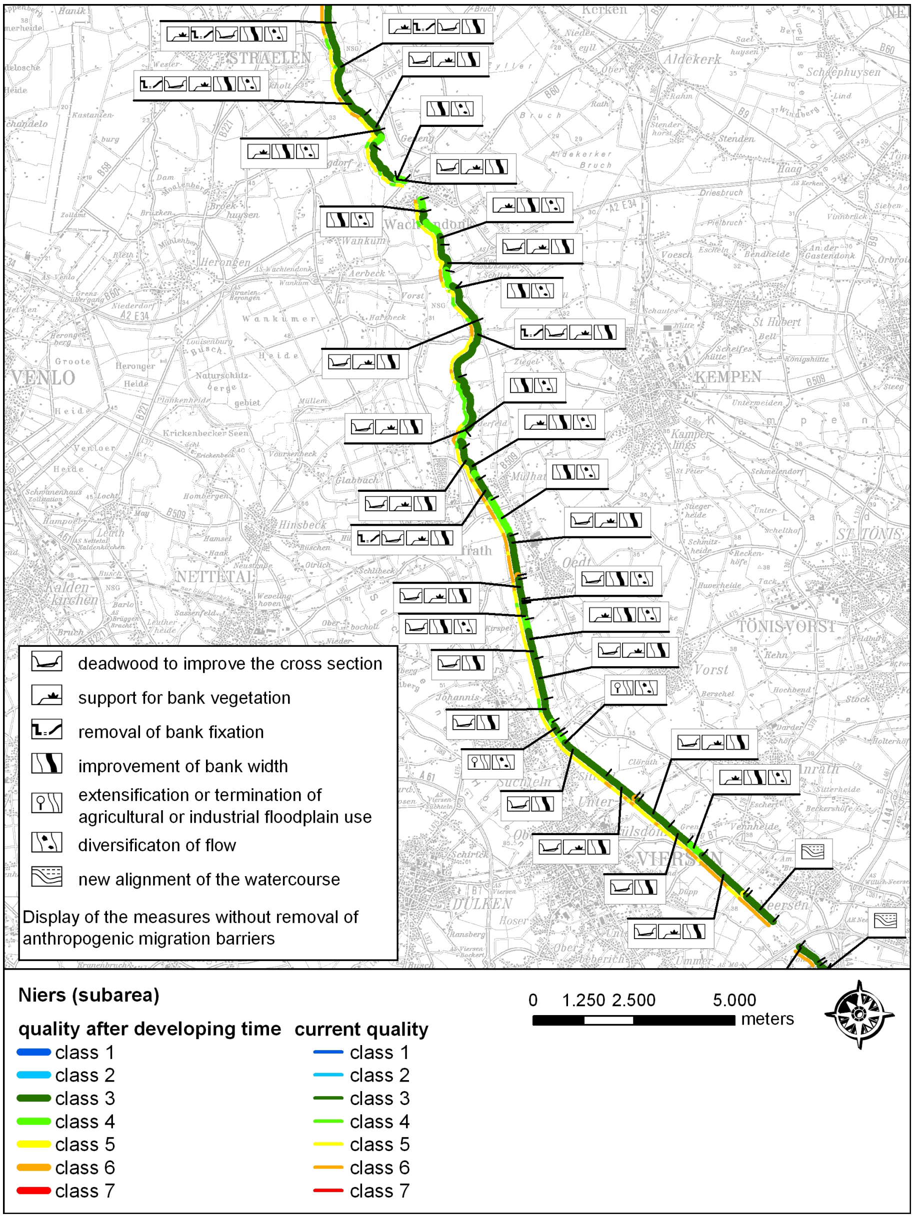

Fig. 2. Map with the results of the DSS for the Niers (subarea).

of the River Niers at present and the predicted results of the DSS WRRL, when the objective of the overall morphological quality should be class 3. The given symbols indicate the proposed measures for the segments between the gray "hatch"-bars. The thick line shows the expected morphological quality class 6 years after the implementation of the measures. The thin line expresses the current morphological quality, thus before the measures are implemented.

5 Conclusions

The aim of the rule-based modelling tool is to support decision makers in selecting the feasible and suitable measures to improve the morphological conditions while taking into account the ecohydrological objectives of the EU WFD.

The identification of the simulation rules is a sophisticated process, since the knowledge on effects of morphological improvement measures is yet scarce and fuzzy. Information from monitoring projects is still rare. That is the reason why North Rhine-Westphalia decided to monitor all future measures so that the basis of the expert rules can be enlarged. While setting up the rules of rule-base 2, it is necessary to generalize the impacts, because detailed effects cannot be predicted at present.

Despite of these problems the developed rule-based system has many advantages. The rules in the tool and the structure of the system can easily be understood. Therefore the results of the model are comprehensible even for a layman. Because of the simple design, the rule-based model can be easily operated and modified. Another advantage is that the rule-bases are very flexible. The rules can be modified without problems according to new knowledge.

The rule-based model is not developed to deliver detailed planning of measures. It rather supports the decision makers in finding the right measures and to identify implementation priorities based on the current situation. The rule-based modelling concept ensures a uniform accomplishment of the programmes of measure in North Rhine-Westphalia (as fare as hydromorphological structure is concerned) since it is based on fixed rules.

The results of the first applications are very encouraging. The next steps of deployment will be done on coupling the rule-based model with a fuzzy fish habitat model to obtain a direct link to the objective of the EU WFD.

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