Appropriate Accuracy of Models for Decision-Support Systems: Case Example for the Elbe River Basin

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Abstract: Given the growing complexity of water-resources management there will be an increasing need for integrated tools to support policy analysis, communication, and research. A key aspect of the design is the combination of process models from different scientific disciplines in an integrated system. In general these models differ in sensitivity and accuracy, while non-linear and qualitative models can be present. The current practice is that the preferences of the designers of a decision-support system, and practical considerations such as data availability guide the selection of models and data. Due to a lack of clear scientific guidelines the design becomes an ad-hoc process, depending on the case study at hand, while selected models can be overly complex or too coarse for their purpose. Ideally, the design should allow for the ranking of selected management measures according to the objectives set by end users, without being more complex than necessary. De Kok and Wind [2003] refer to this approach as appropriate modeling. A good case example is the ongoing pilot project aiming at the design of a decision-support system for the Elbe river basin. Four functions are accounted for: navigability, floodplain ecology, flooding safety, and water quality. This paper concerns the response of floodplain biotope types to river engineering works and changes in the flooding frequency of the floodplains. The HBV-D conceptual rainfall-runoff model is used to simulate the impact of climate and land use change on the discharge statistics. The question was raised how well this rainfall-runoff model should be calibrated as compared to the observed discharge data. Sensitivity analyses indicate that a value of $R^2 = 0.87$ should be sufficient.

***Keywords**: decision-support system; river-basin management; appropriate modeling; rainfall-runoff; Elbe*

1. INTRODUCTION

The Elbe is one of the largest rivers in Central Europe. Water quality in the river is affected by agricultural runoff, while settlements along the river form important point sources of pollution. In terms of shipping density the river is second only after the Rhine in Germany. Planned and ongoing river engineering works aimed at improving the navigability of the river and reducing the risk of flooding include large-scale dike displacement, groyne restoration, and excavation of the river bed and floodplains. Several sections of the river have been designated as protected nature reserves with vegetation types that form a habitat for rare fauna. It is not yet clear how the hydromorphological consequences of the river engineering works will affect the vegetation conditions along the river. The formulation of an optimal management strategy requires in-depth understanding of the interaction of these measures with the social-economic, ecological, and physical processes at different scale levels. Since a methodology and the instruments for integrated river-basin management were not available, the German Federal Institute of Hydrology initiated the project 'Towards a generic tool for river basin management' [De Kok et al., 2000]. The ultimate goal is to develop a prototype decision-support system (DSS), which helps the water managers to formulate an effective strategy for sustainable management of the Elbe river basin. The four functions included in the DSS are: inland shipping, water quality, floodplain vegetation, and flooding safety. In view of the multi-objective nature of the prototype and scale differences of models and data, the choice has been made for a modular design with three scale levels: catchment, main channel (including floodplains), and river section (a section of 20 km). Figure 1 schematizes how the hydraulic and ecological models are integrated in the Elbe-DSS. The research question addressed in this paper is how well a hydrological model should be calibrated in relationship to the accuracy of the floodplain ecology model. The example pertains to a section of the Elbe River near the town of Tangermünde in Saxony-Anhalt, which is where one of the gauge stations is located.

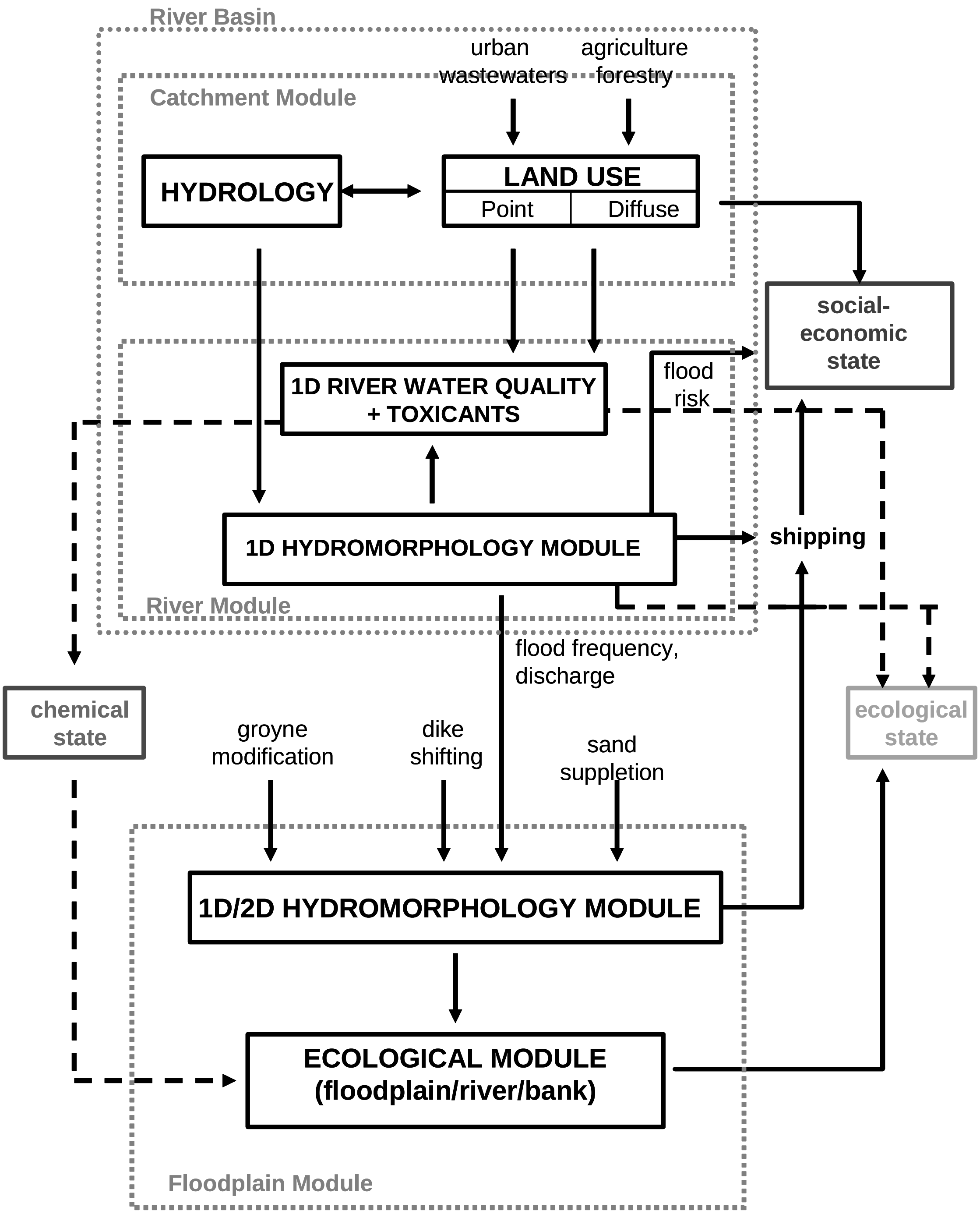

Figure 1. Outline of the integration of models in the prototype decision-support system for the Elbe river basin (dotted lines indicating the three scale levels: catchment, main channel, and river section) [De Kok et al., 2000].

2 MODEL BASE

2.1 Floodplain Ecology

The response of the biotope types in the floodplains to changing hydraulic conditions and river engineering works is based on the rule-based model MOVER (MOdel of VEgetation Repsonse) described by Fuchs et al. [2002]. This model has been developed by the German Federal Institute of Hydrology for the floodplains of the river Rhine and is currently extended to the Elbe River. The model consists of a matrix, with rows indicating the dominant biotope types and the columns indicating the abiotic parameters. MOVER is based on a statistical approach, with the flood duration (total number of flooding days per year) as key input variable. The flood duration is determined from the statistical distribution of the daily average discharge, digital elevation data and water levels in the main channel. The latter are calculated as a function of the discharge by means of a 1D stationary flow model which was calibrated for the Elbe River by Otte-Witte et al. [2002]. The modeled relationship between water level *h* and discharge *q* can be described by a rating curve:

$$h(q) = a\, q^b \qquad (1)$$

where *a* and *b* are parameters. The flood duration is given by

$$N_{year} = \frac{365}{2} \times \left(1 - erf\left(\frac{\ln(q_*) - \mu}{\sigma\sqrt{2}} \right) \right) \qquad (2)$$

where $q_* = (z/a)^{1/b}$ is the critical discharge for inundation of a location with elevation z, and μ and σ are the mean and standard deviation for the daily average discharge. The desired accuracy of the number of flooding days depends on the sensitivity of the ecological model. The rule matrix of MOVER distinguishes differences in the flood duration of ten days per year. For most biotope types even larger ranges in the flood duration will lead to identical maps.

2.2 Rainfall-Runoff

The daily discharge statistics were obtained with historic time series for the period 1964-1995, which have been analyzed by Helms et al. [2002]. The HBV model was developed by Bergström in 1976 [1995]. The initial goal of the HBV model was real-time flood simulation under typical Swedish conditions, which means basins with a large area and an important role for snow. It is a relatively simple model, in which the climate data are transformed into a base-flow discharge and a quick runoff discharge, as shown in Figure 2. Several versions for more specific situations or for more differentiated approaches were developed and nowadays a wide range of applications of the model can be found [Bergström, 1995]. Krysanova et al. (1999) developed the HBV-D model used in this study, in which a basin can be subdivided into subbasins, and a more differentiated land use definition is applied. At the moment, the conceptual hydrological model HBV-D is calibrated for the Elbe river basin.

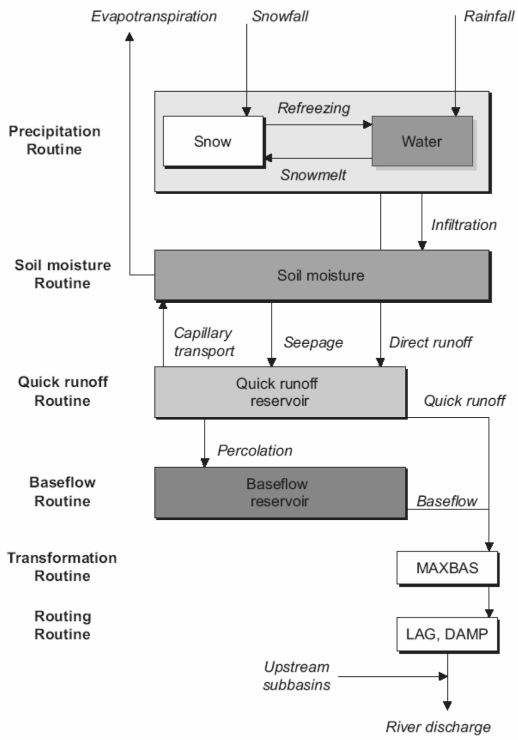

Figure 2: HBV model structure [Van der Wal, 2001].

3 DISCHARGE STATISTICS

The hydrological model will be used to generate discharge time series for the average regime and flood events under various climate change scenarios. The question was raised how accurately the hydrological model should be calibrated on existing data. This is important in view of the effort to be spent on calibration and data collection. A common indicator for the quality of hydrological models is the Nash-Sutcliffe coefficient proposed by Nash and Sutcliffe [1970] and denoted by:

$$R^2 = 1 - \frac{\frac{1}{N_{tot}} \sum_{t=1}^{N_{tot}} (Q_t' - Q_t)^2}{\sigma^2} \qquad (3)$$

where Q_t' and Q_t denote the modeled and historic discharge time series, and σ is the standard deviation. To simulate the output of the HBV model different discharge time series can be generated by adding an auto-correlated noise term ε_t to the original data:

$$Q_t' = Q_t + \varepsilon_t \qquad (4)$$

where

$$\varepsilon_t = \delta_t Q_t + \alpha \varepsilon_{t-1} \qquad (5)$$

with δ_t a scaling factor drawn from a random uniform distribution in the interval [-B, +B], and α the autocorrelation of the difference $Q_t' - Q_t$. In this way the standard deviation of the time series can be changed without affecting the mean of the discharge. This can be expected under changing climate conditions [Booij, 2002]. The reason is that the mean of the distribution will be described correctly by calibration of the water balance. To obtain a reasonable value the parameter α was taken from a calibrated HBV model for the Meuse river basin [Booij, 2002], because the catchments are similar and both the Elbe and Meuse are rainfed rivers. The range B does not depend on the value of α. Its magnitude can be varied to generate discharge time series Q_t' with different values of the quality index R^2. The obvious approach would be to increase the value B until the difference in flood duration for the artificial and historical discharge time series reaches a value approximating the ten-day accuracy required for the MOVER model. Unfortunately, this approach will not result in meaningful estimates for R^2. This can be addressed to the statistical character of the ecological model, which does not match the dynamic nature of the rainfall-runoff model. A discharge time series of poor quality can have a standard deviation close to the value for the historic data. Sensitivity analyses proved that the MOVER model was not very sensitive to the standard deviation of the time series. For the selected location substantial differences in the biotope type distribution occur only for changes in σ larger than 15 %. Hence, a difference of ten days would correspond to unrealistically low values of R^2. For this reason we decided to compare the time series on the basis of the percentage of years, for which the total flood duration did not differ more than ten days from the value for the historic time series i.e.

$$\Delta N_{year} \leq 10 \qquad (6)$$

In anticipation of a vegetation succession model it makes sense to examine the difference at the scale of months as well. Assuming independence of the flood duration between different months the criterion

$$\Delta N_{month} \leq \frac{\Delta N_{year}}{\sqrt{12}} \approx 3 \qquad (7)$$

can be used.

4. CASE EXAMPLE

The parameter values for the selected site near the Tangermünde gauge station (Elbe km 388.2) are given in Table 1 below.

parameter	value
μ (m^3s^{-1})	6.18
σ (m^3s^{-1})	0.56
a	20.97
b	0.061
z (m + sea level)	32.4

Table 1. Discharge and hydraulic parameters for the study site.

Near Tangermünde the flood plains are relatively flat with an average elevation of 32.4 m. above sea level on the right bank. This leads to an average flood duration of twenty-five days per year. Artificial discharge time series were generated by varying the value of B in the range [0.05, 0.30]. For α the value of 0.82 was found for the Meuse river basin [Booij, 2002]. Figures 3 and 4 show the percentage of years and months, which do not satisfy the criteria of (6) and (7) against the value of R^2.

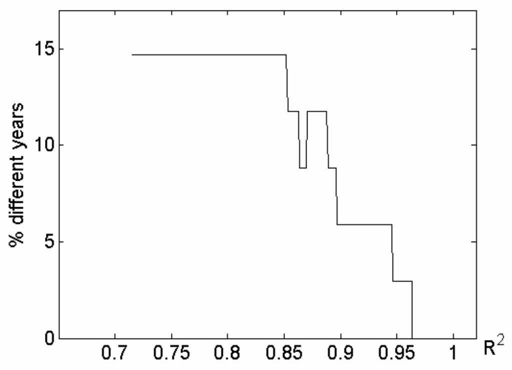

Figure 3. Percentage of years with flood duration that is different according to criterion (6) as a function of R^2.

Depending on what percentage of years or month with different flood duration is accepted one can decide which value of R^2 is sufficient for the rainfall-runoff model. For example, a ten percent difference indicates that R^2 should be around 0.87, which can be considered feasible for the calibration. The corresponding value of B is 0.20.

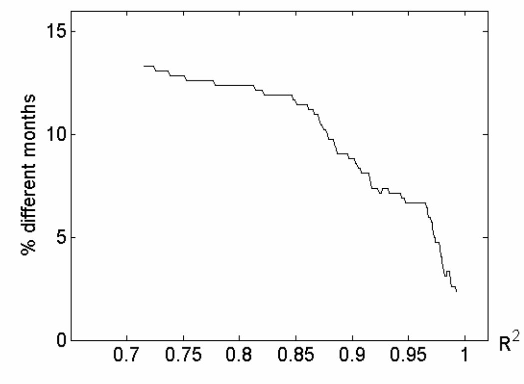

Figure 4. Percentage of months with different flood duration according to (7) as function of R^2.

The step structure of the curves shown in Figures 3 and 4 is a consequence of the definition of R^2, which is based on daily discharge data. Time series differing in R^2 do not necessarily differ according to criteria (6) and (7). Figure 5 shows a sample of 365 days for the observed and simulated times series for a value of $B = 0.20$. In general these results indicate that calibration should be possible in view of the desired accuracy of the discharge distribution, provided one accepts a deviation in the flood duration above the criteria (6) and (7) for 10 % of the months or years. For comparison the calculation was repeated at the level of days as well. A value of $R^2 = 0.87$ turned out to correspond to falsely predicted flooding in 3 % of the days over the 35-year period.

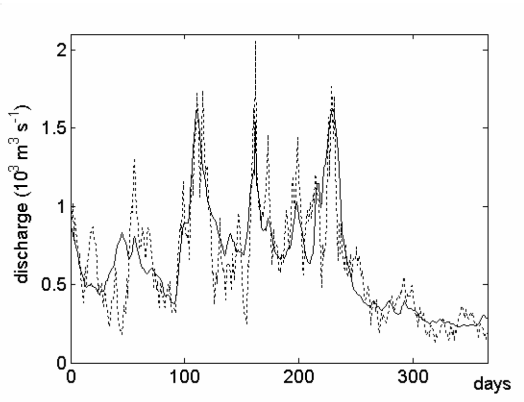

Figure 5. One-year sample of observed (solid) and simulated (dashed) discharge time series.

5. CONCLUSIONS

There exist no scientific standards to measure when it is appropriate to integrate different models in a decision-support system. This makes the design an ad-hoc process. This problem becomes more prominent when statistical and dynamic models are used in combination. The integration of a dynamic rainfall-runoff model with a statistical model for the biotope types of the floodplains along the Elbe River served as a case example to show how the problem could be addressed. The sensitivity of the ecological model for changes in the discharge statistics proved to be low. In this case direct sensitivity analyses will be of limited use to determine the required quality of the input discharge time series. Instead it is better to compare simulated discharge time series of different quality with historic data. Depending on the sensitivity of the ecological model for changes in the discharge distribution one can formulate a criterion for the acceptable accuracy of the time series. This will indicate how good the rainfall-runoff model should be calibrated. For the study site at Tangermünde calibration seems feasible at the level required for predicting vegetation response.

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