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Fuzzy-rule based metamodeling of nitrate transport in large catchments

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Especially for nutrient balance simulations, physically based ecohydrological modeling needs an abundance of measured data and model parameters, which for large catchments all too often are not available in sufficient spatial or temporal resolution or are simply unknown. For efficient large-scale studies it is thus beneficial to have methods at one's disposal which are parsimonious concerning the number of model parameters and the necessary input data. One such method is fuzzy-rule based modeling, which compared to other machine-learning techniques has the advantages to produce models (the fuzzy-rules) which are physically interpretable to a certain extent, and to allow the explicit introduction of expert knowledge through pre-defined rules.

The study focuses on the application of fuzzy-rule based modeling for nitrate transport simulation in large catchments, in particular concerning decision support. To be able to construct such models it is possible to take a well-calibrated physically based model to produce data. This metamodeling approach replaces missing observed data. Thus, in a first step the ecohydrological model SWAT was calibrated for a 1000 km^2 study area in Northern Germany and used to produce the needed data for rule training.

Taking into account the different pathways of nitrate emission from soils (surface runoff, interflow, leaching to groundwater), a modular setup was chosen for the fuzzy model. Two modules were created for each pathway, one for the calculation of fertilized soils and one for non-fertilized soils. Adding one module for groundwater and one for river runoff yields a model consisting of eight modules in total. After selection of appropriate input variables (seven to nine variables for each module) the modules were trained using the SWAT data and simulated annealing as a discrete optimization method. Although flow components are of major importance when describing nitrate transport, they also imply a dependence on (deterministic) water budget calculations. Therefore two versions of the fuzzy model were created, one employing the flow components and one using precipitation only. The fuzzy models are operated on a monthly time step.

Both versions show a good reproduction of the SWAT nitrate loads at the catchment outlet with the flow version expectedly yielding superior results, but the no-flow version still in a viable range (Nash-Sutcliffe-Efficiency/volume error: 0.83/12.7% and 0.63/26.6% respectively). The fuzzy models were validated on different study areas and on land use change scenarios with satisfying results.