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Stochastic hydro-economic modelling for groundwater nitrate pollution control under uncertainty. Application to El Salobral-Los Llanos case study, Spain

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A stochastic hydro-economic modelling framework is presented for determining management strategies against groundwater nitrate pollution from agriculture under uncertainty. The main goal is to contribute to the ongoing policy process in the European Union (Water Framework and Groundwater Directives) providing a tool for deriving fertilizer standards to reduce groundwater nitrate pollution while maximizing the benefits in agriculture within an uncertain environment that increase the reliability of polices for meeting the groundwater quality targets.

The uncertainties on groundwater nitrate pollution stem for a wide range of processes, such as nitrate leaching; groundwater parameters that drive the pollutant fate and transport; to uncertainty on the crop yield and farmer's decisions such as fertilizer applications rates, land use / crop pattern scenarios; or unknown future economic scenarios affecting crop and fertilizer prices and subsidies. Different approaches were developed to tackle the diverse uncertainties, based on three methods: a Monte Carlo optimization method, a procedure to find the spatial distribution of crops that maximize the total profit while meeting the WFD quality standards, and finally, a two-step optimization-simulation process that entails an a priori probability distribution of the values of the uncertain parameter or decision variable taken from a deterministic optimization. The optimization step relies upon a management optimization model that determines the spatial and temporal fertilizer application rate that maximizes net benefits in agriculture constrained by the quality requirements in groundwater at various control sites. Crop yield and nitrogen leaching functions are derived from agronomic simulations, which together with the crop prices allow obtaining the profits in agriculture. Numerical groundwater flow and solute transport simulation models are used to develop unit source solutions that are assembled into a pollutant concentration response matrix. The integration of the response matrix in the constraints of the management model allows simulating by superposition the evolution of groundwater nitrate concentration over time at different points of interest throughout the aquifer resulting from multiple pollutant sources distributed over time and space (Peña-Haro 2009, 2010). The modelling framework relates fertilizer loads (i.e. what can be controlled) with nitrate concentration in groundwater (i.e. what is regulated by the WFD). The simulation step involves Monte Carlo simulations of the uncertain parameter and/or decision variable, which allows obtaining the probability of achieving groundwater standards and additional insight into risk assessment.

The framework has being applied to the Salobral-Los Llanos case study (Mancha Oriental aquifer, Spain). The application shows the importance of taking into account such uncertainties in order to assess the reliability of certain policies and define more reliable policies, and analyze the model sensitivity to the unknown parameters or decision variables and the trade-offs between higher economic returns and reliability in meeting the environmental standards. In this sense, the application of the method to the case study has shown that higher profits can be achieved while meeting the WFD standards. In addition, the profits are significantly more sensitive to the uncertainty in the distribution of the land uses than to the other sources of uncertainties.

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