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Assessment of impacts of land use and climate changes on groundwater resources

Manuel Pulido-Velazquez (1), Juan Pablo Rivera (2), Carlos Llopis-Albert (3), Salvador Peña-Haro (4), Alberto Garcia-Prats (5), Juan Manuel Jorques (6), and David Pulido-Velazquez (7)

(1) Department of Hydraulics and Environmental Engineering. Universidad Politécnica de Valencia, Valencia, Spain (mapuve@hma.upv.es), (2) Department of Hydraulics and Environmental Engineering. Universidad Politécnica de Valencia, Valencia, Spain (juaricai@doctor.upv.es), (3) Department of Hydraulics and Environmental Engineering. Universidad Politécnica de Valencia, Valencia, Spain (cllopisa@gmail.com), (4) Institute of Environmental Engineering, ETH Zurich, Switzerland (pena@ifu.baug.ethz.ch), (5) Department of Hydraulics and Environmental Engineering. Universidad Politécnica de Valencia, Valencia, Spain (agprats@upvnet.upv.es), (6) Department of Hydraulics and Environmental Engineering. Universidad Politécnica de Valencia, Valencia, Spain (juajorro@cam.upv.es), (7) 3 Instituto Geológico y Minero de España (IGME), Granada, Spain (d.pulido@igme.es)

A methodology and a modelling framework are proposed to evaluate the impact of future land use and climate changes on sustainable groundwater management in agricultural areas. The methodology is based on the integration of different models (including hydrologic, economic and agronomic simulation), GIS, remote sensing information, and techniques for the definition of the future climate and land use scenarios.

The methodology allows assessing the impact of the different scenarios on groundwater quality and quantity, as required by the EU Water Framework and Groundwater Directive. This entails the integration of response functions from a series of different models, which are embedded into a holistic hydro-economic model for assessing the economic impact of the changes and the economic benefits from different adaptation policies.

The land use scenarios are generated taking into account their demands and the spatial location of their changes. Future land use is determined through the IMAGE projections, which are based on the scenarios developed by the IPCC report (2000), including their environmental impacts. The spatial location of land use changes relies on a cellular automata simulation, a powerful tool for the dynamic modeling of land use change. The potential change of a cell is defined by means of a logistic regression model. The cell allocation rules for agriculture are defined according to the crop yields, the economic results, water availability and simulated environmental impacts.

A GIS-based SWAT model is used to simulate rainfall-runoff under current and future climate and land use scenarios. The land use tool in Arc SWAT is used for introducing the different land use scenarios, while meteorological and agronomic inputs are modified for simultaneously simulating the new climate change conditions. The combined effects are translated into different groundwater recharge values and other hydrologic budget components.

A GIS-based version of the agronomic simulation model EPIC (GEPIC) is used to estimate crop yields and nitrate leaching functions for different crops at different sites under the new climate change and land use scenarios. The benefits in agriculture can then be derived through crop production and crop prices, and expected costs and subsidies.

The new groundwater recharge and nitrogen input values fed groundwater flow and transport simulations using MODFLOW and MT3D, which are run for the different scenarios providing a pollutant concentration response matrix for each one. 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 control sites throughout the aquifer resulting from multiple pollutant sources distributed over time and space. In this way, the modelling framework relates the fertilizer loads with nitrate concentration at the control sites as in Peña-Haro et al. (2009, 2010). Different policies (fertilizer standards, fertilizer prices, etc.) can be then simulated. The use of the hydro-economic optimization framework allows defining optimal fertilizer standards in order to meet the groundwater quality standards in the new (climatic and land use) conditions.

The methodology is being applied to the Mancha Oriental groundwater body, in Spain. The aquifer, hydraulically connected to the Jucar river, is being intensively exploited mainly for irrigated agriculture, and the intense use of fertilizers is increasing groundwater nitrate concentration at certain sites. The comprehensive information from remote sensing images of more than 25 years, processed by the IDR-University of Castilla La Mancha, has been used for determining the crop evolution pattern and historical recharge to the aquifer. The future climate scenarios are based on time series of climatic variables longer than 30 years over several meteorological stations, for the scenario A1B defined by the IPCC for an ensemble with 5 runs for the same Regional Climatic Model (RCA3) but different Global Circulation Models, provided by the Swedish Meteorological and Hydrological Institute (SMHI).

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