



QGIS-SWAP-Paddy: a modelling framework to simulate irrigation and aquifer recharge in lowland rice area. First application to the Lomellina rice district (northern Italy)

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Rice-growing regions underlain by shallow aquifers require irrigation strategies that simultaneously satisfy crop water demand, sustain groundwater recharge, and ensure an appropriate response to the increasingly frequent occurrence of water scarcity in many geographical areas. Traditional approaches, typically based on field-scale experiments or conceptual water-balance models, struggle to represent the complex interactions among irrigation practices, soil-water-crop processes, and groundwater dynamics at broader spatial scales.

To address this limitation, we developed QGIS-SWAP-Paddy, a novel GIS-integrated modelling framework for simulating lowland agricultural systems across multiple spatial scales. The framework couples a semi-distributed SWAP (<https://www.swap.wur.nl/>) based agro-hydrological model with a channel-network module embedded within the QGIS environment. Simulations are driven by thematic maps and information stored in a GeoPackage database, including soil data, land use, irrigation management, groundwater depth, and agro-meteorological conditions. This architecture enables the systematic integration of diverse inputs — maps, time series, field measurements, parameter estimates for soil hydraulic properties, crop development, and alternative irrigation management — into a coherent modelling workflow.

The framework has been applied to the Lomellina region in northern Italy, located in the largest rice-growing district in Europe. After calibration and validation, initial applications of QGIS-SWAP-Paddy highlight its capacity to support scenario analyses for contrasting irrigation strategies, including wet seeding with continuous flooding, dry seeding with delayed flooding, and Alternate Wetting and Drying (AWD). The system is designed to be integrated with external models — most notably MODFLOW (<https://www.usgs.gov/software/modflow-6-usgs-modular-hydrologic-model>) — to simulate groundwater flow and quantify the impacts of irrigation management on aquifer dynamics. This coupling, currently being developed within the PROMEDRICE project (<https://promedrice.org/>; PRIMA-Section2-2022), will enable comprehensive assessments of water-reuse mechanisms and groundwater sustainability in rice-based irrigation systems.

QGIS-SWAP-Paddy produces both aggregated outputs (e.g., time series of irrigation requirements and deep percolation at domain or sub-domain scale) and spatially explicit outputs such as maps of first-aquifer recharge, representing a powerful tool for scientific research and operational decision-support in lowland irrigated agricultural areas.