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Accounting for co-evolutionary interactions between human and water systems in a spatially explicit, loosely-coupled hydrological and land-use model

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Co-evolutionary interactions exist between human and water systems. The state of the water systems is often a determining factor in making socioeconomic decisions while the decisions taken often in turn influence the water systems. Both recent spatially explicit physical-based hydrological models and spatially explicit socioeconomic models have tried to address these interactions. However, typically this only involves a unidirectional coupling between the two systems. The results of a hydrological model are either forced into a socioeconomic model, or conversely, the results from a socioeconomic model are used as inputs for a hydrological model. The drawback of this unidirectional approach is that it fails to capture the co-evolutionary interactions, since there is no feedback between both systems. Models that account for such feedbacks are either not spatially explicit (i.e. the observed phenomena are aggregated for the whole study area), fully integrated within a single modeling environment and formalism (e.g. developed purely in system dynamics or agent-based formalism), or formulated in a tightly-coupled manner (i.e. the model components cannot exist independently).

This study provides a proof of concept for a bidirectional, loosely-coupled, and spatially explicit coupled human-water systems model. The bidirectional nature of the approach involves dynamic state and time integration between the models and thus establishes explicit feedbacks between them. The loosely-coupled nature allows the use of models that have different formalisms and have been developed in different modeling environments. Specifically, a distributed hydrological model that simulates rainfall-runoff and flooding phenomena is coupled with a land use change model that applies a utility-based suitability framework. The hydrological model uses the PCRaster Python package while the land use change model uses LandUse Scanner software which is implemented in GeoDMS. The bidirectional loose coupling approach reduces the time needed to develop the model, maximizes the utilization of domain specific model functionality, and enables co-evolutionary interactions to emerge.

As a case study, the interactions between the water system and the society's land use change decisions in Chau Phu, one of the district within the Vietnam Mekong Delta, are simulated. The results show that the decreasing temporal and spatial extent of flooding over time creates a shifting pattern from double-rice cropping to triple-rice cropping practices by the local farmers. As a further consequence, the higher soil exploitation rate by triple-rice cropping practices over time deteriorates soil quality and in turn annual yields.