Appendix 2: Linking ABM with SWAT

Once all farmer adoption status is updated, the ABM output in the abstract grid file provides the adoption status for every farmer in every period and is used to make the necessary updates in relevant input files of SWAT in the Sandusky watershed file. Abstract grid cell characteristics are assigned to Sandusky watershed locations by the smallest computational unit of SWAT, HRUs. SWAT is then run for the whole simulation period (1970-2010) to provide water quality metrics such as sediment and phosphorus loads. The input files for SWAT are all in ASCII text format, making it easy to interface with the ABM and this linkage is supported with the MatLab programming language.

For each year, farmers' decisions regarding conservation practice adoption are used to modify several SWAT input files. For example, if a farmer adopts non-structural practices such as no-till instead of conventional tillage, the land management input file (.mgt) in SWAT is modified to reflect this change. Similarly, if a farmer adopts structural practices such as filter strips, the operations input file (.ops) is updated with a filter strip of 10 m width. Because farmers receive economic incentives to adopt structural practices, their continued use of filter strips is expected. For enrollment in land retirement programs, we change the land cover type in the input file (.mgt) to be one of the perennial covers such as big bluestem without fertilizer application. Once a farmer enrolls in land retirement programs, adherence to the contract is mandatory for at least 10 years as a requirement of the program. If a farmer adopts nutrient management plan, then a 20% reduction in fertilizer application rate is assumed. This change is also reflected in the management input file of SWAT (.mgt).

The decision algorithm used by our farmers includes social and spatial networks, which influence their adoption decisions. Throughout the simulation period, farmers are programmed to observe their neighbors and the conservation practices they adopt. Therefore, in our model, the process of conservation practice adoption has the necessary spatial component and shows variance in each simulation. For the purposes of illustration, we reported the average load reductions from numerous simulations but also included the variability in error bars (Figures 5-6, main text). Due to the stochasticity built-in the model, in each ABM initialization, different farmer types are assigned to each farmer, which results in different decision-making characteristics. Each ABM run result has different spatial locations for conservation practices. The initial spatial distribution of farmer types affects the social and spatial network structure and has thus an impact on the final spatial distribution of adopted practices. For example, if a farmer located in the downstream part of the watershed adopts a conservation practice, its impact on water quality would be different than adopting a practice in the upstream part of the watershed. To eliminate this initial condition bias, we perform numerous ABM runs and link those to SWAT, which yields differences in water quality metrics as well; hence the bars demonstrate this impact of the different implementation locations of the conservation practices.

Challenges of Linking Agent-based Models with Biophysical Models

This framework is designed to investigate the impact of alternative policy approaches and changing land tenure dynamics on farmer adoption of conservation practices intended to increase the water quality. For this purpose, we chose to link SWAT with ABM for farmer adoption of conservation practices. Because SWAT is a river basin scale water quality model developed to assess the water quality benefits of conservation practices (Gassman et al. 2007; Osmond 2010), linking it with ABM aligns with the purpose of our framework.

For this framework, we chose a loose integration method, which uses the state variables from one model as a driving variable in the other model (Antle et al., 2001). ABM determines the land management pattern for the Sandusky watershed and SWAT estimates water quality metrics as a function of the updated land management pattern. One of the disadvantages of using loosely coupled models is the computational overhead associated extracting output files and modifying input files. We used MatLab programming language to link ABM output and modify necessary SWAT input files. Single SWAT run including the modification of input files for 41 years (1970-2010) averaged about 55 minutes when run on quad-core Windows machine. Because of the stochasticity built in the model, we performed 25 simulations and reported the averages of these runs for water quality metrics, which resulted in approximately 1,375 minutes or 0.95 days.

In this framework, we aimed to represent the farm-scale decision-making regarding conservation practice adoption. However, due to limited data, representation of the exact location of farms and long-term management decisions is not possible. Therefore, we constructed an abstract ABM without the spatial representation of decision-making process which could affect the farmers' conservation decisions because soil properties and slope of their land are not influential in their adoption decisions.

The capabilities of SWAT were the determining factor for the scale of the linked model. We developed a fine-scale SWAT model to match the average farm size in the Sandusky basin (Daloğlu et al., 2012). However, SWAT is not developed on grid cells and the smallest computational unit of SWAT, HRU cannot be manually delineated which complicates the representation of farm level decision making.

Linking social and biophysical models for social-ecological system representation is profoundly valuable, especially in evaluating plausible policy scenarios. While the recent land use and land change research has contributed to this endeavor, this study goes one step further by linking a widely used water quality model to ABM to better represent the dynamic interactions of farmers.

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