Hydrol. Earth Syst. Sci. Discuss., 6, C3441–C3451, 2010
www.hydrol-earth-syst-sci-discuss.net/6/C3441/2010/

Hydrology and
Earth System
Sciences
Discussions

Interactive comment on "Accessible integration of agriculture, groundwater, and economic models using the Open Modeling Interface (OpenMI): methodology and initial results" *by* T. Bulatewicz et al.

T. Bulatewicz et al.

tombz@ksu.edu

Received and published: 5 March 2010

Reviewer Comment
"First, there is little evidence of historical memory given the fact that water use in irrigated agriculture has been the prime focus of many of these integrated models, going back to the 1960s when resource economists developed the first optimal control (demand management) groundwater models for irrigated agriculture (e.g. Burt 1964, 1966). The European Water Framework Directive (WFD) requires an economic

analysis, but not necessarily an integrated policy model, although integrated modeling is expected to become an increasingly important information tool to support policy and decision-making in the WFD (Brouwer and Hofkes, 2008; Brouwer and de Blois, 2008)."

Author Response
You are correct that combined water and economic models have a long history and were among the first attempts at integrating models across disciplines. This literature is reviewed by Harou et al. (2009), Kondouri (2004), and Brouwer and Hofkes (2008). As Harou et al. point out, one of the criticisms of previous integrated models is that they have drastically simplified certain model components and spatially aggregated the base data. For instance, the hydrologic relationships are often reduced to simple mass balance equations that update the water stock between periods over a large region. This is particularly true when models are integrated in a holistic manner. Explicit hydrologic models can predict spatially detailed water level changes that are often relevant for management decisions at a regional scale. Such models are better accommodated by modular integration. We view our contribution as one of the first studies to utilize a standardized, modular linking interface that provides automated execution and data exchange between multidisciplinary models without requiring them to be modified. We have added a discussion of this as a new section 2.2.4 titled "Related Work".

Changes to the Manuscript
Add to page 7221, line 27, with new section heading "2.2.4 Related Work":
"Within the disciplinary context of integrating agricultural, groundwater, and economics models, there has been considerable research dating back to the 1960's (Burt, 1964, 1966). This literature is reviewed by Harou et al. (2009), Kondouri (2004), and Brouwer and Hofkes (2008). As Harou et al. point out, one of the criticisms of previous integrated models is that they have drastically simplified certain model components and spatially aggregated the base data. For instance, the hydrologic relationships are

often reduced to simple mass balance equations that update the water stock between periods over a large region. This is particularly true when models are integrated in a holistic (Braat and Lierop) manner in which a single model simulates all disciplinary processes endogenously (i.e. economic and hydrologic equations are solved simultaneously). Explicit hydrologic models can predict spatially detailed water level changes that are often relevant for management decisions at a regional scale. Such models are better accommodated by modular (or compartmental) integration (Braat and Lierop) in which independent models transfer data. Data is either transferred in one direction from one model to another, or there is a bidirectional exchange.

Data transfer between models has been realized in different ways with varying levels of automation. Draper (2003) used an economic model to estimate economic benefit and loss functions that were then used as input to a water resource optimization model. In Volk et al. (2008), ecological and economic models exchanged data through an intermediary GIS that stored model inputs and outputs. Ahrends (2008) coupled a groundwater model to an economic model employing a custom program that executed the models and translated input/output files in an automated fashion. The IWRAM DSS (Jakeman and Letcher 2003) employed a variety of modular approaches, from creating component models in a common programming language or software tool allowing them to be executed together, to creating an integrating engine that executed customized models written in different languages (Cuddy et al. 2005).

Two of the fundamental challenges of the modular approach are (1) identifying the appropriate data exchanges and (2) enabling the models to transfer data (Brouwer and Hofkes 2008; Cai 2003). Our work is one of the first studies to utilize a standardized, modular linking interface that provides automated execution and data exchange between multidisciplinary models without requiring them to be modified.

New References:

Ahrends, H., M. Mast, Ch. Rodgers, and H. Kunstmann. 2008. Coupled hydrological-economic modelling for optimised irrigated cultivation in a semi-arid catchment of West Africa. Environ Modell Softw. 23(4). 385-395.

Braat, L. C., and W. F. J. van Lierop (Eds.) (1987), Economic-ecological modeling. Elsevier. 329 p.

Brouwer, Roy Hofkes, Marjan, 2008. Integrated hydro-economic modelling: Approaches, key issues and future research directions, Ecological Economics, 66(1), 16-22.

Burt, O. R. (1964). Optimal resource use over time with an application to groundwater. Management Science 11: 80-93.

Burt, O. R. (1966). Economic control of ground water reserves. Journal of Farm Economics 48: 632-647.

Cai, X., D. C. McKinney, and L. S. Lasdon. Integrated Hydrologic-Agronomic-Economic Model for River Basin Management. J. Water Resour. Plng. and Mgmt. 129, 4-17. 2003.

Cuddy, S. M., Saguantham, P., Letcher, R. A., Croke, B. F. W. and Saifuk, K. (2005). IWRAM DSS - a modelling approach for integrated water resources assessment and management in northern Thailand. In: Kachitvichyanukul, V., Purintrapiban, U., and Utayopas, P. (eds) SIMMOD 05 International Conference on Simulation and Modelling 2005. Nakornpathom, Thailand, pp 299- 308. Asian Institute of Technology, Bangkok, Thailand.

Draper, A. J., M. W. Jenkins, K. W. Kirby, J. R. Lund, and R. E. Howitt. 2003. Economic-engineering optimization for California water management. Journal of Water Resources Planning and Management. 129(3). 155-164.

Harou, J. J., M. Pulido-Velazquez, D. E. Rosenberg, J. Medellin-Azuara, J. R. Lund, and R. Howitt (2009), Hydro-economic modeling: Concepts, Design, Applications and Future Prospects, Journal of Hydrology, 375, 334-350.

Jakeman, A. J. and Letcher, R. A.: Integrated assessment and modelling: features, principles and examples for catchment management, Environ. Modell. Softw., 18(6), 491–501, 2003. 7215

Volk, M., J. Hirschfeld, A. Dehnhardt, G. Schmidt, C. Bohn, S. Liersch, P. W. Gassman. 2008. Integrated ecological-economic modelling of water pollution abatement management options in the Upper Ems River Basin. Ecological Economics. 66(1). 66-76.

Reviewer Comment

"Second, the economic model is not really a standard economic model in the classical sense. It is a statistical model that allows calculation of crop choice shares given specific values for the independent variables, not an economic optimization model minimizing production costs and/or maximizing yield benefits to achieve an economically efficient (optimal) solution in groundwater resource allocation decisions. In practice, hydrological simulation models are usually coupled to economic optimization models. This is not the case in the study presented here. The results from the policy scenario analysis are as expected: groundwater use goes down as its use is regulated or incentivized (restricted in both cases). However, whether these scenarios represent the economically most efficient solutions is unclear. An important advantage

of economic optimization is that the policy or decision-maker is given information about the least cost way to reach environmental objectives or about maximum crop yields respecting environmental objectives, in this case related to groundwater recharge rates to avoid overexploitation.

It is also not clear from the paper what role crop prices play in the modeling approach. From an economic point of view, the trade-off in the decision-making process is between pumping costs and crop yields and the relevant question is at which point marginal (pumping) costs equal marginal benefits (crop prices). The presented economic model seems to be driven ('triggered') primarily by the availability of water (water level change), not crop prices and net benefits (e.g. where pumping costs presumably go up as a result of decreasing water levels or opportunity costs of groundwater well depletion etc)."

Author Response

In this study, our focus is on the behavior of individual landowners and their responses to different policies. We rely on the neoclassical theory of optimizing behavior at an individual level, from which we derive the land use equations that were econometrically estimated. Of course, an alternative approach would be an explicit optimization model that mimics each landowner's annual decision process. We chose the econometric approach here to obtain adequate spatial disaggregation in our predictions. To predict choices at the well level using an explicit optimization model, one would have to parameterize a separate version of the model for each well location. While there are techniques to do this (e.g., Howitt, 1995) they are not as well developed as the econometric approach, nor do the existing methods apply easily to cases where multiple years of data are available on each production site as is the case here. A separate scenario altogether from the result of individual decisions is the outcome under the social planner's problem, which optimizes discounted net benefits from water use over the entire study region. As the aquifer is a common property resource, the results of individual decisions will diverge from the planner's solution. As you point out, a valuable piece of information from solving the planner's problem would be the estimated cost of groundwater exploitation to the region. Previous studies that solved the planner's problem did so by choosing aggregate water use to maximize discounted income. We are unaware of published studies that have solved the planners' problem in a disaggregated setting such as ours. Doing so would be computationally intensive (though, in principle, still feasible), as the planner's choice variables would be a vector of water use at each of the withdrawal points over the 14 years of study. Because of its complexity, we leave the disaggregated planner's problem to future research.

Regarding the role of crop prices, the economic model embodies a tradeoff between benefits or crop revenue, which depends on crop prices, against production costs, which depend on the cost of applying water and increases as the aquifer is depleted. Here the economic model focuses on land use, and the agronomic model (EPIC) simulates the actual amount of irrigation water pumped after the crop has been selected. (The EPIC model includes a procedure to schedule irrigation events given a particular production setting, and the parameters that govern this procedure were estimated from observed water-use patterns in the study region (Bulatewicz et al. 2009).). Revenue of each crop is determined by its expected price and its expected yield, which in turn depend on site-specific factors such as soil type. Variation in production costs of a particular crop can be explained by variation in the application cost of water, which depends on variation in energy prices and in pumping lifts (we use aquifer saturated thickness as a proxy for pumping lift, as it as the two variables have a one-to-one relationship). Given the current prices of the various crops, pumping costs, and site specific factors that are known to the farmer can calculate expected income per acre from each of the crops and is assumed to choose the income maximizing alternative. In addition there are unobserved variables that are random to the researcher, which create "noise" in this decision and only allow us to make probabilistic statements about which crop would be chosen under each combination of the observed variables. These

probabilistic statements are the multinomial logit equations. This theoretical framework is explained in Steward et al. (2009) and Hendricks (2007) and identifies the regressors in the equations we estimated therein. As also explained in those sources, the coefficients on these regressors have the expected marginal effects on the probability of selecting the various crops. As time progresses, the crop choice decision is affected by aquifer depletion because saturated thickness declines and raises pumping costs. These changes have the greatest impact on water-intensive crops such as corn and alfalfa, making them less attractive compared to water-extensive crops such as sorghum.

Changes to Manuscript

Section 2.2.3 now reads as follows:

"The economic model predicts irrigators' land-use choices on irrigated fields each year. A common modeling approach in the groundwater economics literature is an optimization procedure (e.g., mathematical programming) structured to reproduce a land manager's annual decision process (Bernardo et al, 1993a,b; Burness and Brill, 2001; Young et al., 1986). Such models typically maximize profits subject to land- and water-use constraints. Here, we follow a common method from the literature on the economics of land use (Hardie and Parks, 1997; Lichtenberg, 1989; Wu et al., 2004), in which land use choices are predicted by probabilistic equations that were econometrically estimated from land managers' observed choices. The two methods are conceptually equivalent, as the form of the probabilistic equations is derived under the assumption of individual optimization. The econometric approach was selected for our study because of the field-specific nature of the land use data, where the observed decisions are typically the 'corner solutions' of planting all available land to a single crop. These data are not well suited to the available techniques for calibrating optimization models (e.g., Howitt, 1995).

The modeling framework is described by Hendricks (2007) and Steward et al. (2009). Irrigators are assumed to choose the crop on each field that maximizes expected income – i.e., expected crop revenue less production costs. Revenue of each crop is determined by its expected price and its expected yield, which in turn depend on site-specific factors such as soil type. Variation in production costs of a particular crop can be explained by variation in the application cost of water, which depends on variation in energy prices and in pumping lifts. The probability of a particular crop being planted is assumed to be an increasing function of its expected income. The multinomial logit model (Maddala, 1983) was applied to estimate functions that relate the probability of each crop being planted to the underlying causal factors (crop prices, energy prices, pumping lift, and other site-specific variables). Data to estimate the model consisted of 1956 field-level observations from the study region spanning the period 1991–2004. This dataset contains records on irrigated fields in the county that were planted to the four most common irrigated crops: alfalfa, corn, sorghum, and soybeans. Once estimated, the logit equations constitute the simulation model to predict land use choices in the study region. When invoked for a particular simulation year, the model randomly assigns one of the four crops to each irrigated parcel, where the logit equations and field-level data govern the probability that each crop is selected.

New references:

Bernardo, D. J., H. P. Mapp, G. J. Sabbagh, S. Geleta, K. B. Watkins, R. L. Elliott, and J. F. Stone. 1993a. Economic and environmental impacts of water quality protection policies 1. Framework for regional analysis, Water Resources Research 29(9): 3069–3079.

Burness, H.S. and T.C. Brill. 2001. The role for policy in common pool groundwater use. Resource and Energy Economics 23: 19-40.

Howitt. R.E. 1995. Positive mathematical programming. American Journal of Agricultural Economics 77: 329-342.

Young, R.A. , J.T. Daubert, and H.J. Morel-Seytoux. 1986. Evaluating Institutional Alternatives for Managing an Interrelated Stream-Aquifer System. American Journal of Agricultural Economics 68: 788-797.

Reviewer Comment

“A third and final issue that puzzled me a bit was the role of rainfall and variations herein on the water stock at the beginning and end of each simulated time period over the 15 year time horizon due for example to climate change. The model clearly is dynamic, but the issue of stock replenishment in the simulation process remained a bit unclear to me, and related to that - and despite the extensive discussion of model calibration - perhaps the issue of uncertainty, for instance related to the unpredictability of weather conditions, but also model parameters remained slightly underexposed. Not having full insight in trends in precipitation patterns, and as a result water scarcity and the shadow price of water, makes it harder to understand what triggers the ’decision’ for crop choices and final model output: water scarcity, changes in crop prices, pumping costs or other input factors. An interesting extension of the model would have been to estimate groundwater shadow prices. However, this is only possible if an economic optimization model would have been used.”

Author Response

Regarding stock replenishment, the groundwater model currently uses a long-term average recharge. This conceptual model was chosen as recharge is formed from the quantity of precipitation (averaging 0.5 inches per year recharge out of 15-20 inches of precipitation) that migrates downward through the root zone and then a very deep vadose zone. Thus, precipitation events are greatly buffered in the vadose zone before they reach the groundwater table. It is foreseeable that recharge may change over long-term climate change, but the academic community has not yet arrived at consensus as to what this impact may be. For example, agricultural irrigation specialists still argue as to whether corn production increases recharge (because irrigation is applied) or decreases recharge (because corn creates such a negative pressure gradient). This has been clarified in the text.

Regarding uncertainty, weather variation (from climate change or otherwise) mostly impacts the crop model, and dictates how much water must be pumped from the aquifer to grow a crop. Since this was a retrospective study, we used observed weather conditions over the simulation period and chose not to investigate alternate conditions. Uncertainty with respect to the model parameters is investigated in the calibration studies of the individual models cited in the text.

Changes to Manuscript
Add to 7220, line 21:
"The groundwater model uses a long-term average recharge."

Add to 7223, line 28:
"Recharge to the aquifer from the agricultural model was not explicitly represented in the linkages as recharge past the root zone to the aquifer is buffered through a very deep vadose zone that dampens surficial signals."

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 7213, 2009.