Interactive Drivers of Land-Cover/Land-Use Change in the Upper Mississippi River Basin (Part III)

An Integrated Modeling System of Climate, Conservation Policy, and Land Manager Choices

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Introduction

Nonpoint source pollution has resulted in extensive degradation of soil and water quality in the Upper Mississippi River Basin (UMRB). Research is focusing on the environmental and economic impacts of conservation policy drivers, and the climate change drivers, and how these drivers affect land managers' decisions towards land cover and land use changes. To implement this, an integrated modeling framework has been established that incorporates a watershed based hydrologic and water quality model called SWAT (Soil and Water Assessment Tools; Gassman et al., 2007), economic models, and climate models. This study focuses on quantifying errors caused by the resolution of climate models and eliminating biases caused by climate models in predicting meteorological inputs to the hydrologic model.

UMRB and the Modeling Framework

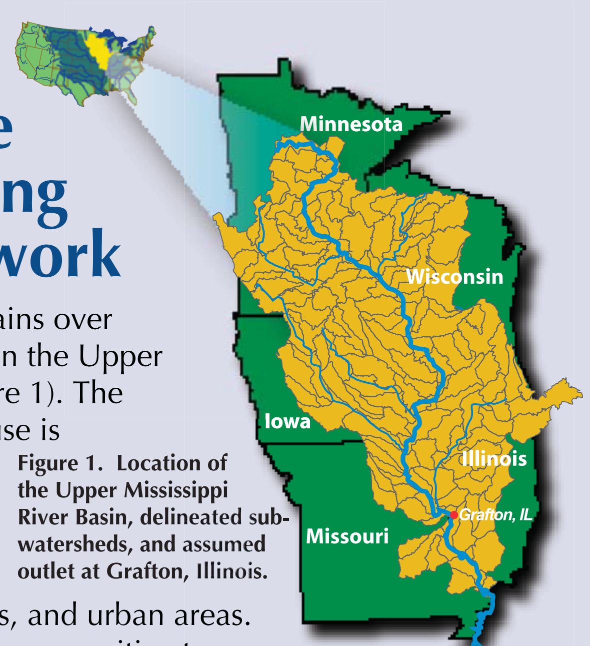

Figure 1. Location of the Upper Mississippi River Basin, delineated sub-watersheds, and assumed outlet at Grafton, Illinois.

The UMRB drains over 490,000 km2 in the Upper Midwest (Figure 1). The primary land use is agricultural (nearly 65%) followed by forest (20%), wetlands, lakes, and urban areas. The UMRB is very sensitive to climate change, because of the intersection within the region of the three air masses (pacific, Arctic, and Gulf of Mexico) that control the climate of North America.

We integrate spatially detailed economic models of agricultural land use choices with SWAT and climate models to study the costs and water quality benefits of environmental conservation policies under existing climate conditions and under a series of projected climate change scenarios.

Completed Work

We presented the modeling setup and preliminary results on impacts of conservation policy driver and climate change driver at previous NASA Science Team Meetings in 2006 and 2007. This modeling setup includes UMRB delineation into 131 subwatersheds (USGS 8-digit HUCs) and further delineation into over 2,500 hydrologic response units based on soil and land management data from USDA's National Resources Inventory (NRI). The unit of analysis is NRI survey points (114,000 in UMRB) that range from a few hundred to several thousand hectares in size of homogeneous land use, soil and land management. SWAT model calibration and validation was performed for streamflow and water quality components at the watershed outlet (Jha et al., 2006). An initial set of conservation policy scenarios were developed and the economic and environmental benefits were assessed (Kling et al., 2006). Preliminary evaluation of the impact of climate change on UMRB hydrology was presented in previous posters.

Current Progress

Two features of GCMs that impede their ability to represent climate as required by SWAT are coarse resolution and model bias. We use both contemporary climate (for the period of 1961-2000) as well as future climate results (A1B emission scenarios for the period of 2046-65) of ten GCMs (Figure 2) available in the IPCC Data Archive (PCMDI, 2007) to assess the impacts of these two features.

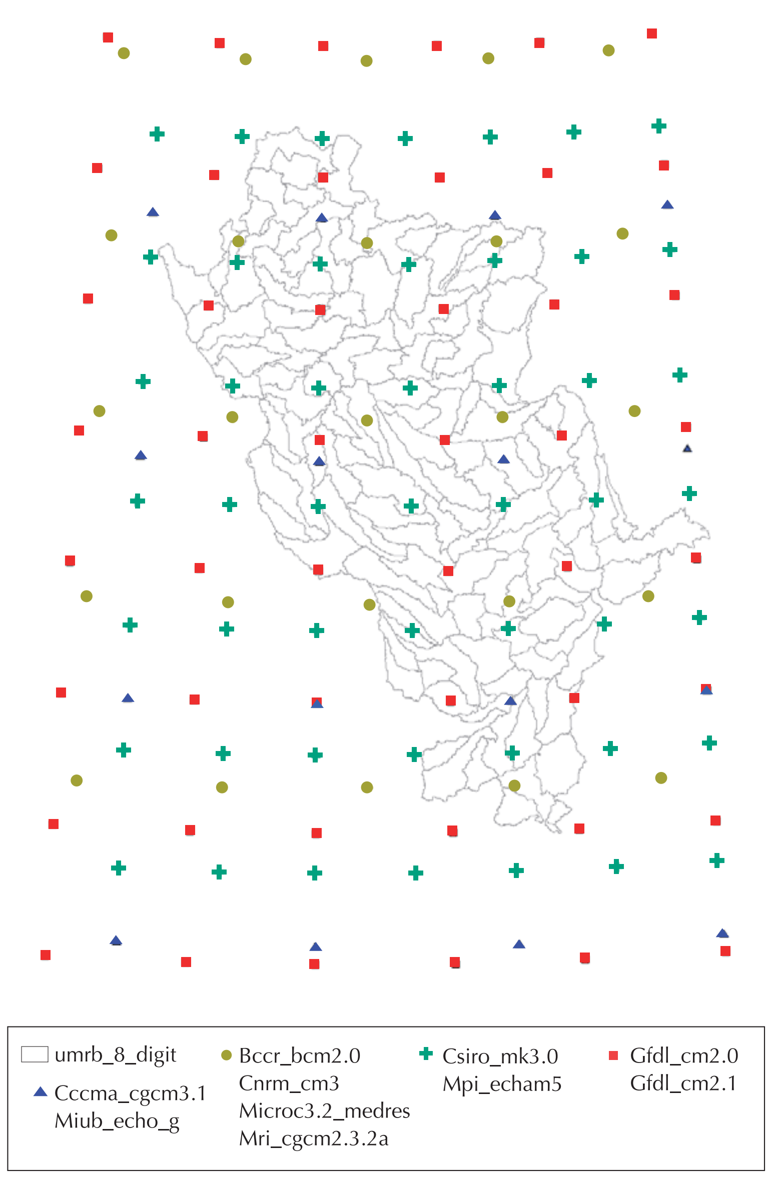

Figure 2. Ten GCMs used in this study from IPCC data archive.

Influence of Model Resolution

We degraded the high-resolution observations (weather stations used in the baseline calibration) by using only those points closest to the GFDL model grid points (17 points within UMRB) as input to SWAT. With this degraded observed climate data, streamflow at Grafton, Illinois is uniformly reduced from March through September (Figure 3). The trend is a better comparison for the low-resolution GFDL contemporary simulations. With GFDL contemporary input, SWAT produces excessive streamflow in all months (with maximum error of about 300% in April) and the trend is far from the "degraded" streamflow trend. This suggests that a major source of error in the GFDL model other than resolution.

Influence of Model Biases

We compensated for model biases of temperature by computing the differences of monthly means between the model contemporary climate and the observed climate and subtracting these from the daily values produced by the model. We used the same correction for both contemporary and future scenario climate. For precipitation, we computed the ratio of model-to-observed monthly mean. Corrected precipitation values were determined by dividing daily model values by the appropriate monthly correction ratio.

A major reduction in streamflow is created by this correction so that the error is approximately 20% rather than 300% in the cool season and almost no change in error in the warm season (Figure 4). Further analysis reveals that annual precipitation was corrected downward by 10% but snowfall was corrected down by slightly over 50% and surface runoff downward by slightly under 50%.

Similarly bias correction was performed for all ten GCMs and the results are averaged to get "GCM Mean" (Figure 5). This bias correction had a major impact on streamflow for the cold season but had almost no impact on the warm season.

Climate Change

For the future climate, all models show very modest changes in precipitation, with MRI_CGCM2.3.2a having the largest change with a 7.5% decrease. We corrected each model for its biases in meteorological variables and used the results to simulate SWAT for the future scenario climate of 2046-2065. An overall comparison shows essentially no change in streamflow and retention of the essential seasonal features (e.g. major peak in May, broad minimum in mid to late summer and minor peak in November) of the current climate.

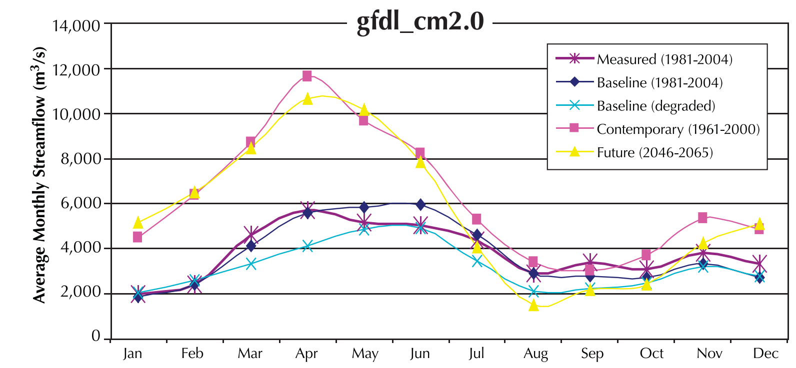

Figure 3. Mean monthly UMRB streamflow at Grafton, Illinois.

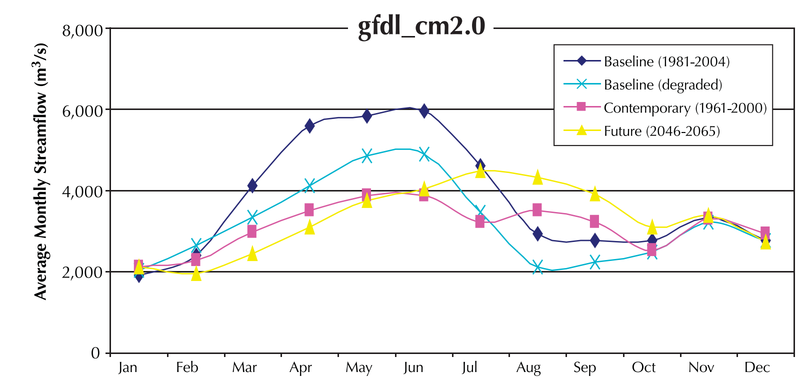

Figure 4. Mean monthly UMRB streamflow at Grafton, Illinois with bias correction.

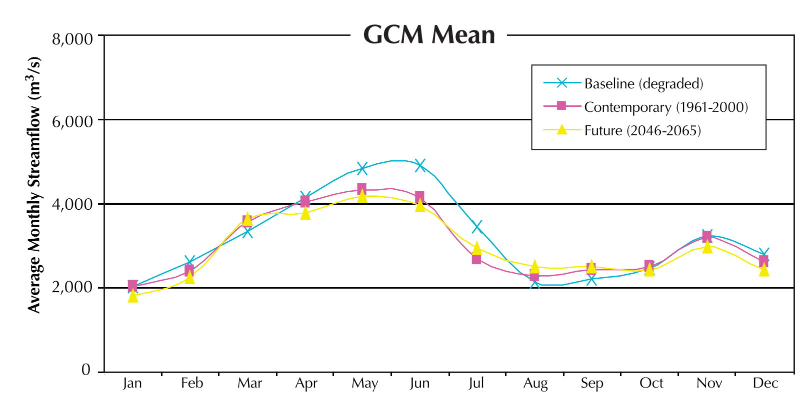

Figure 5. Mean monthly UMRB streamflow at Grafton, Illinois for GCM mean with bias correction

Ongoing Work

An optimization tool called an evolutionary algorithm is currently being tested to combine with the SWAT UMRB modeling setup and conservation practice cost data to develop a tradeoff frontier for the UMRB. This frontier will provide an array of solutions, each specifying the least cost of achieving targeted nutrient (nitrogen and phosphorus) reductions and the corresponding locations of the agricultural conservation practices within the watershed. Further analysis will be performed on selected optimal solutions with future climatic conditions predicted by selected climate models.

References

Gassman, P.W., M. Reyes, C.H. Green, and J.G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans. ASABE 50(4): 1211-1250. http://www.card.iastate.edu/environment/items/asabe_swat.pdf.

Jha, M., P.W. Gassman, S. Secchi, and J.G. Arnold. 2006. Upper Mississippi River Basin modeling system Part 2: Baseline simulation results. In: Coastal Hydrology and Processes (Eds. V.P. Singh and Y.J. Xu) pp. 117-126, Water Resource Publications, Highland Ranch, CO.

Kling, C.L., S. Secchi, M. Jha, H. Feng, P.W. Gassman, and L.A. Kurkalova. 2006. Upper Mississippi River Basin modeling system Part 3: Conservation practices scenarios. In: Coastal Hydrology and Processes (Eds. V.P. Singh and Y.J. Xu) pp. 117-126, Water Resource Publications, Highland Ranch, CO.

PCMDI. 2007. Program for Climate Model Diagnosis and Intercomparison. <http://www-pcmdi.llnl.gov/> (assessed January 2008)

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