

CLIMATE CHANGE INDUCED STREAMFLOW IN THE UPPER MISSISSIPPI RIVER BASIN

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1. INTRODUCTION

Water quantity, and hence quality, in rivers and lakes are sensitive to climate changes. Past studies on climate change effects on basin scale streamflow and quality have been based on general circulation model (GCM) projections that fail to represent important mesoscale convective precipitation systems and small scale hydrological regimes. In addition, such studies were typically carried out on small basins. Very few studies used regional output covering large basins. In this study, regional climate model that generated two 10-year simulated climates for the Continental U.S. corresponding to current and future scenario climates at 50-km horizontal resolution (Pan et al., 2001) was used to derive a hydrological model, SWAT (Soil and Water Assessment Tool), over the entire UMRB (Upper Mississippi River Basin).

The objective of the study was to quantify the effect of future climate on streamflow in the UMRB. Observed streamflow of the period 1979-1988 was used to evaluate the combined performance of SWAT and RCM models. And then effect on streamflow was evaluated for change in climate. The study will develop a better understanding of how the aquatic systems functions under different climate conditions, and hence will be useful to water managers.

2. MATERIALS

Pan et al. (2001) has generated a suite of RCM simulations corresponding to current and future climates over the continental U.S. The archived climate variables include precipitation, winds, temperature, humidity, solar radiation, snowpack, soil moisture. Etc. The dataset were archived for two 10-year scenario periods: 1990s and 2040s on 50-km grids at 3-hr intervals. The RCM simulations provide spatial distribution of precipitation, snow depth, soil moisture, etc.

The fine-resolution climate change information is more realistic than those past GCM based ~300 at monthly temporal intervals since the RCM resolve the basin scale topography, mesoscale storms, etc. These RCM simulations (precipitation and temperature) were used as input to the SWAT model.

SWAT is a physically based model offering distributed parameters, continuous time simulation, and flexible watershed configuration. It is a watershed scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land uses, and management conditions over long periods of time (Arnold et al., 1998). In SWAT, a watershed is divided into subwatersheds with unique soil/landuse characteristics that are further divided into hydrologic response units (HRUs). The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2m), shallow aquifer (typically 2-20m), and deep aquifer (>20m). Flow generation, sediment yield, and non-point-source loadings from each HRU in a subwatershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Model components can be divided into the following: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management. Hydrology process is based on the water balance equation:

$$SW_t = SW + \sum_{t=1}^t (R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

where SW is the soil water content minus the 15-bar water content, t is time in days, and R , Q , ET , P , and QR are the daily amounts of precipitation, runoff, evapotranspiration, percolation, and return flow; all units are in mm. Hydrology processes simulated include surface runoff estimated using SCS curve number; percolation modeled with a layered storage routing technique; lateral subsurface flow; groundwater flow to streams from shallow aquifers; potential evapotranspiration by the Hargreaves method; snowmelt; transmission

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P2.19

losses from streams; and water storage and losses from ponds.

SWAT has a large number of adjustable parameters relating to land use and vegetation for each sub-basin. Basic input from RCM result was daily precipitation and maximum/minimum temperatures over the entire UMRB. The model also requires topographic, soil, land use, and management data. Detailed inputs include data on stream channels, shallow aquifers, ponds, reservoirs, point sources, etc. Information on topography, land use and soil were obtained from BASINS (Better Assessment Science Integrating point and Nonpoint Sources) model (BASINS, 2001). BASINS integrates a geographic information system (GIS), watershed and climatological data, and state-of-the-art environmental assessment and modeling tools in one convenient package.

3. METHODS

Three experiments label as OBS, CTL, and SNR were carried out (Table 1) for the purpose of evaluating the combined performance of SWAT and RCM in simulating observed flow (OBS) and to evaluate changes in streamflow that can be expected to accompany change in climate (comparison of SNR and CTL).

The UMRB watershed was delineated using the ArcView interface of the SWAT model (called AVSWAT). The model has the capability of generating stream network based on the DEM data, and then subwatersheds are delineated based on the delineated stream network. Accuracy of the delineated stream network depends upon the accuracy level of DEM data. Once the threshold drainage area and the watershed outlet are specified in the mode, it automatically delineates the stream network and subwatersheds using ArcView functionality. Threshold area is the minimum drainage area required to form the origin of the stream. The UMRB constitutes 431,000 km² up to the point just before the confluence of the Missouri River into the Mississippi River (i.e. at Mississippi river at Grafton) (Figure 1). A total of 119 subwatersheds were delineated that follow the boundaries of the USGS defined 8-digit HUCs (Hydrologic Unit Codes). Stream network provided by the USGS (in BASINS package) was used as a reference to accurately delineate stream network and hence the subwatersheds. This is very important as it is related to the water routing process. Several trial and error runs were performed to bring delineated stream network closer to the USGS referenced

stream network. Stream outlets were also adjusted (deleted and added) to bring subwatersheds size very close to 8-digit HUC watersheds boundaries.

4. RESULTS AND DISCUSSION

The model was validated using the results of RCM model as OBS (see Table 1). These data were generated using observation/measured data to serve as lateral boundary conditions. As demonstrated in Pan et al. (2001), this run's precipitation is a good proxy to observed precipitation in the UMRB region.

Preliminary results from OBS run indicate that SWAT performed quite well even without any model calibration. Predicted average annual streamflow values at the Grafton, Illinois (the outlet of delineated UMRB) were within 10 percent of the measured values. Figure 2 shows the annual variability of streamflow reproduced by the SWAT. Simulated streamflow peaks in April and has a minimum in September, as observed. The model tends to overshoot the spring peak while underpredict fall magnitude. This bias pattern of streamflow in SWAT corresponds to the bias of the simulated precipitation by the RCM.

Another aspect of change in streamflow with climate change is the interannual variability, which is masked in the 10-year composite streamflow. SWAT captured the intrannual variation quite well, showing a wet period from 1982-1986 and dry years for remaining years (Figure 3). As cautioned in the SWAT user's manual, the first year results (1979) should be considered suspect due to spin-up effects.

The long-term change in streamflow changes directly depends on change of precipitation. The RCM simulated precipitation in the UMRB, showing an increase throughout the year except for sporadic decrease in periods of a few days (Figure 4), is in consistent with general wetting of the atmosphere (IPCC, 2001). Most persistent increase occurs in spring, possibly related to more active mesoscale convective systems. The climate induced streamflow changes are inferred by evaluating differences between the CTL and SNR runs. Change in streamflow due to climate change increases significantly. The largest increase occurs in the late winter (more than doubling) and in summer (Figure 5).

Changes in precipitation and streamflow demonstrated quite different patterns and magnitudes. It is interesting to compare their annual distribution as shown in Figure 6. The mean change in annual precipitation is a 16%

P2.19

increase whereas streamflow increase is 64%. These non-proportional changes suggest the complication by other components of water flow budget, such as evapotranspiration and runoff changes.

5. CONCLUSION

Forced by regional climate model simulated precipitation and temperature, even without model calibration, the SWAT model can simulate streamflow reasonably well on a monthly basis. The SWAT simulated streamflow tends to be overpredicted in fall, a general bias feature with RCM simulated precipitation. This seems to suggest that the streamflow errors largely come from input data. The climate change in precipitation drives climate change in streamflow in a nonlinear way due to the complications of direct thermal effects.

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REFERENCES

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. *Large area hydrologic modeling and assessment, Part I: Model development*. J. Amer. Water Res. Assoc., 34:73-89.

BASINS. 2001. U.S. Environmental Protection Agency, Office of water, Washington, DC. <http://www.epa.gov/OST/BASINS/index.html>.

IPCC. 2001. *Climate Change 2001 – The scientific bases*. Houghton, J., T.Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden and D. Xiaosu (Eds), Cambridge University Press, 944pp.

Pan, Z., J.H. Christensen, R.W. Arritt, W.J. Gutowski, Jr., E.S. Takle, F. Otieno. 2001. *Evaluation of uncertainties in regional climate change simulations*. J. Geophys. Res., 106(D16):17,735-17,751.

Table 1 Description of experiments and forcing lateral boundary conditions.

<i>Runs</i>	<i>Description of RCM forcing</i>
OBS	Observation (1979-1988)
CTL	Hadley Centre GCM control run (around late 1990's)
SNR	Hadley Centre transient GHG run (around 2050's)

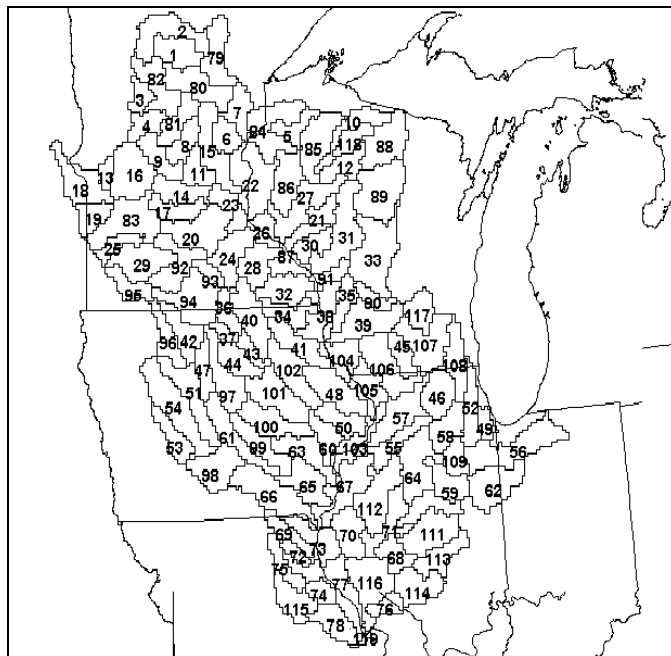


Figure 1 Delineation of 119 subwatersheds of Upper Mississippi River Basin.

P2.19

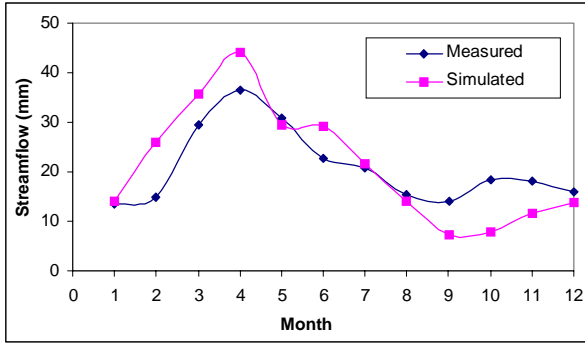


Figure 2 Validation of ten-year composite monthly streamflow at Grafton, Illinois simulated by SWAT.

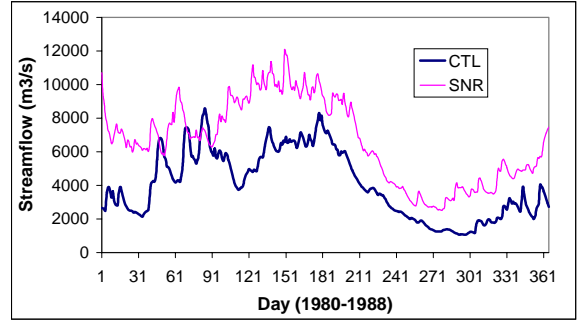


Figure 5 Comparison of climate change in streamflow simulated by SWAT.

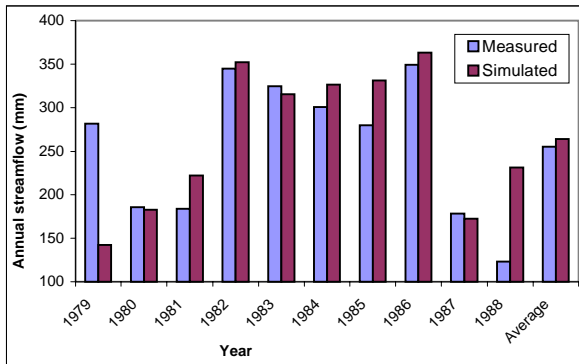


Figure 3 Comparison of interannual variability of streamflow at Grafton, Illinois.

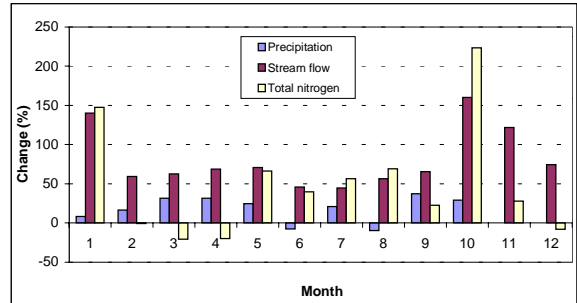


Figure 6 Comparison of climate changes in precipitation, streamflow, and total nitrogen loading.

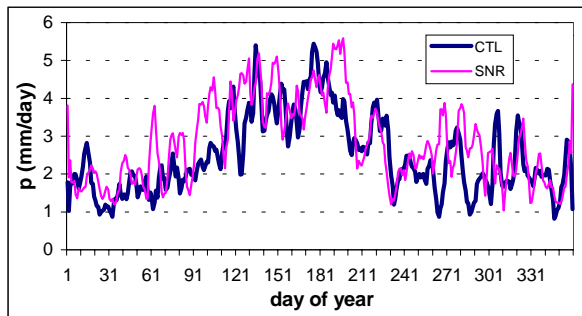


Figure 4 Comparison of climate change in precipitation simulated the RCM.