Multiple model comparison to predictions of watershed streamflow and nutrient discharges

Xuyong Li*, Latif Kalin, Kathleen B. Boomer*** and Donald E. Weller*****

*State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-environmental Sciences, Chinese Academy of Sciences, Shuangqing Road 18, Beijing, 100085, China
** School of Forestry and Wildlife Sciences Auburn University**,** Auburn, AL 36849-5418, USA
***Smithsonian Environmental Research Center, 647 Contees Wharf Road, P. O. Box 28, Edgewater, Maryland 20137-0028, USA

Keywords: Multiple model comparison; nutrient discharge, watershed

Watershed models are widely utilized to assess effects of future land use and/or climatic scenarios on water quality. They are useful tools in identifying development scenarios with the least negative impact on water quality out of many probable future development scenarios. However, model predictions do not reflect the uncertainty associated with the model itself (Vrugt et al., 2005). Model comparison has been recognized as a valuable strategy for assessing and communicating the uncertainty associated with model structures (Breuer et al., 2009).

In this study, we applied three watershed models (SWAT, GWLF and HSPF-CBP5) to predicting flow and nutrient discharges from small watersheds of Chesapeake coastal plain in the United States of America. Among six modeled watersheds, we used three of them (SERC 304, SERC 310 and Greensboro) for model calibrations, and other three watersheds (SERC 305, SERC 306 and Ruthsburg) for model validations. We also implemented model validation with different time period than calibration at the Greensboro watershed.

Among the three watershed models, SWAT (Soil and Water Assessment tool) is a semi-distributed, process-based, long-term hydrologic and water quality model (Arnold et al., 1998). GWLF (the Generalized Watershed Loading Functions) is a lumped parameter watershed model that predicts streamflow and the loads of sediment, nitrogen and phosphorus (Haith and Shoemaker, 1987). GWLF requires least number of parameter and data inputs among the three models. The Chesapeake Bay Program's HSPF Phase 5 application (HSPF-CBP5) (Linker, 2000) is based on a lumped parameter simulation model that uses hourly meteorological data to drive water transport and storage through watershed segments. Nutrient and sediment loads in response to management practices for major land uses are simulated with integrated sub-models. The HSPF-CBP5 model is highly parameterized and data intensive. We averaged the model predictions for each variable from each single model. Each model was assigned a weight factor using the following equation:

$$\lambda_{i,j} = \frac{e^{\left(Ens_{i,j}-1\right)}}{\sum_{i=1}^{n} e^{\left(Ens_{i,j}-1\right)}}$$

in which *Ens* is the Nash–Sutcliffe efficiency obtained from validation results, *i* is the model number with *n* being the total number of models used. The *j* index indicates the type of constituent (flow, TN and TP). *S*uperior models are assigned higher weights. Model outputs were multiplied with their corresponding weighting factors and then summed to obtain weighted averages.

All three models showed best prediction performance for flow, then total nitrogen (TN) and worst for total phosphorus (TP). The model performance for the three models varied among different watersheds and among different variables. No one model consistently outperformed the other two (Table 1). For the calibration and validation watersheds, the relative difference between model prediction was 5%-38%

for streamflow, 6%-51% for total nitrogen (TN), 13%-50% for total phosphorus (TP). SWAT model had Nash-Sutcliffe efficiencies of 0.54~0.73 for monthly streamflow, 0.36~0.59 for monthly TN and -1.66~0.38 for monthly TP; GWLF model had Nash-Sutcliffe efficiencies of 0.60~0.77 for monthly streamflow, 0.47~0.61 for monthly TN and -0.92~0.36 for monthly TP; HSPF-CBP5 model had Nash-Sutcliffe efficiencies of 0.34~0.73 for monthly streamflow, 0.34~0.77 for monthly TN and -0.07~0.45 for monthly TP For the validation watersheds.

Table 1. Annual average flow, TN and TP discharges from observation, SWAT, GWLF and HSPF-CBP5 model predictions and single model performance indicated as Nash–Sutcliffe efficiency.

	Watershed & Time period	Variable	Observed	Model Average	Relative Difference(%)	Model performance (Ens) for monthly predictions		
						SWAT	GWLF	HSPF-CBP5
Calibration watersheds	Greensboro 1984-1999	Flow (cm)	38.6	40.3	8	0.67	0.70	0.73
		TN (kg N/ha/yr)	6.89	7.31	22	0.49	0.59	0.73
		TP (kg P/ha/yr)	0.36	0.43	29	0.11	0.30	0.45
	SERC 304 1989-1992	Flow (cm)	29.4	31.8	17	0.67	0.77	0.66
		TN (kg N/ha/yr)	7.34	8.22	40	0.36	0.56	0.49
		TP (kg P/ha/yr)	0.88	0.78	38	0.26	-0.30	0.10
	SERC 310 1990-1995	Flow (cm)	43.6	41.5	5	0.69	0.73	0.75
		TN (kg N/ha/yr)	18.8	17.7	14	0.54	0.61	0.77
		TP (kg P/ha/yr)	0.96	0.85	13	-1.66	-0.92	-0.07
Validation watersheds	Greensboro 2000-2005	Flow (cm)	51.9	51.8	9	0.66	0.68	0.70
		TN (kg N/ha/yr)	8.41	8.20	6	0.44	0.47	0.55
		TP (kg P/ha/yr)	0.68	0.54	29	0.06	-0.08	0.39
	Ruthsburg* 2000-2005	Flow (cm)	48.1	50.2	9	0.61	0.62	0.63
	SERC 305 1989-1992	Flow (cm)	36.8	38.2	20	0.73	0.60	0.64
		TN (kg N/ha/yr)	10.3	11.5	36	0.44	0.50	0.57
		TP (kg P/ha/yr)	0.78	0.86	50	0.38	-0.05	0.18
	SERC 306 1989-1992	Flow (cm)	28.6	30.0	38	0.54	0.60	0.34
		TN (kg N/ha/yr)	9.24	9.25	51	0.59	0.55	0.34
		TP (kg P/ha/yr)	0.99	1.55	22	0.21	0.36	0.10

* Only flow data was available at this site.

We conclude that no one model was superior to others when SWAT, GWLF and HSPF-CBP5 models were applied to predicting streamflow and nutrient discharges. Model averaging is helpful to reduce the risk of prediction errors caused by the model structure of any single model.

References

Arnold J.G., Srinivasan R., Muttiah R.S., and Williams J.R. (1998) Large area hydrologic modeling and assessment. Part I: Model development. *J. Am. Water Res. Assoc.* **34**, 73–88.

Breuer L., Huisman J.A., Willems P., Bormann H., Bronstert A., Croke B.F.W., et al. (2009) Assessing the impact of land use change on hydrology by ensemble modeling (LUCHEM) I: Model intercomparison of current land use. *Adv. Water Resour.* **32**, 129-146.

Haith D.A. and Shoemaker L.L. (1987) Generalized watershed loading functions for streamflow nutrients. *Water Resour. Bull.* **23**, 471–478.

Vrugt J.A., Diks C.G.H., Gupta H.V., Bouten W., and Verstraten J.M.(2005) Improved treatment of uncertainty in hydrologic modeling: combining the strength of global optimization and data assimilation. *Water Resour. Res.* doi:10.1029/2004WR003059.

Linker L., Shenk G., Dennis R., and Sweeney J. (2000) Cross-media models of the Chesapeake Bay watershed and airshed. *Water Qua. and Ecos. Mod.* **1**(1–4):91–122.