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Uncertainty-based evaluation and comparison of SWAT and HSPF applications to the Illinois River Basin

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SUMMARY

The Soil and Water Assessment Tool (SWAT) and the Hydrologic Simulation Program-Fortran (HSPF) are two river basin simulation models with similar scheme of watershed delineation and functionalities. Both have been selected as modeling tools to support decision and policy making in management of the Illinois River Basin, the United States. This paper reports results calibrating and evaluating SWAT and HSPF model to hydrologic data in the Illinois River Basin, with relative performance of two models in hydrologic simulation and model behaviors under calibration being further compared. In this study, two different calibration approaches, the multi-criteria and the generalized likelihood uncertainty estimation (GLUE) method, were used to quantify uncertainties originated from the use of multi-site discharge observations and the presence of equifinal solutions. It is concluded that both models achieved satisfactory performance after the calibration, and the parameter identification of each model was subject to considerable uncertainties. Furthermore, there exist parameter sets that enable the HSPF model to generate more accurate predictions of the discharges in the main stem of the Illinois River than the SWAT model does, but when the two models were run in un-calibrated mode the distributions of the model fit summary statistics for HSPF observed in the Monte Carlo sampling during GLUE calibration are more varied than those for SWAT with heavier tails on the inferior side and SWAT would have comparable performance to HSPF on average. This finding implies that the accuracy that the HSPF model can achieve in a modeling exercise may have more reliance on the efficacy of the calibration procedure, and the application of SWAT may have some advantage when calibration data are lacking or scarce.

1. Introduction

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) and the Hydrologic Simulation Program-Fortran (HSPF) are two comprehensive river basin models with similar functionalities. Both provide an integrated framework for modeling various hydrological and water quality processes. In recent years, a large volume of SWAT and HSPF applications have been reported in the literature (Eheart and Tornil, 1999; Bracmort et al., 2006; Green et al., 2007; Goncu and Albek, 2007; Lian et al., 2007, 2010; Xie et al., 2008; Ferrari et al., 2009; Mishra et al., 2009; Ryu, 2009; White et al., 2010). Developed as watershed models with general applicability, the SWAT and HSPF model need to be calibrated and the performance of the calibrated models should be carefully evaluated before they are put into predictive uses. For these reasons, model calibration and evaluation often became a major theme in published studies pertaining to SWAT and HSPF models (e.g., White and Chaubey, 2005; Gallagher and Doherty, 2007; Iskra and Droste, 2007; Tolson and Shoemaker, 2007; Green and van Griensven, 2008). Moreover, the similarity between the SWAT and HSPF models naturally raises interest in their comparison and selection. In reality the choice of a model often depends on the modeler's past experience and personal preference, but efforts have been made to compare the relative strength of these two models through their parallel application. Van Liew et al. (2003) evaluated the SWAT and HSPF models in hydrologic simulation of eight nested agricultural watersheds within the Little Washita River Experimental Watershed and two adjacent agricultural watersheds in southwestern Oklahoma. Singh et al. (2005) applied both SWAT and HSPF to model the hydrology of the Iroquois River Basin in Illinois and Indiana and compared the performance of the two models. Other SWAT vs. HSPF comparison studies, which involved the simulation of various water quality constituents (sediment, nutrients, bacteria, and pesticides) were reported by Saleh and Du (2004), Im et al. (2007), Nasr et al. (2007), Parker et al. (2007), and Chin et al. (2009).

In this paper, we presents a study calibrating and evaluating SWAT and HSPF model to hydrologic data in a middle-sized river basin in the Midwest of the United States, the Illinois River Basin

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(IRB), with relative performance of two models in hydrologic simulation and model behaviors under calibration being further compared. The Illinois River is a major tributary of the Mississippi River and is also a focus area of watershed management and ecological restoration in the United States. Both SWAT and HSPF were selected as the major modeling tools to support decision and policy making in this endeavor.

Various techniques have been developed for calibration and evaluation of hydrologic models. The traditional approach aims at finding a uniary set of estimates for uncertain model parameters given a predefined criterion of optimality. This approach is straightforward, but provides no treatment on or indication to the uncertainties that arise from model parameter estimations. In the study reported in this paper, two more sophisticated calibration schemes, the multi-criteria approach (Gupta et al., 1998) and the generalized likelihood uncertainty analysis (GLUE) method (Beven and Binley, 1992), were implemented. Behind the two approaches there is a shared philosophy. Rather than seeking a single "optimal" set of parameters, both approaches identify a collection of parameter sets to accommodate the uncertainties due to the non-uniqueness in model parameter estimation. On the other hand, the multi-criteria and GLUE approaches are proposed to handle two different types of parametric uncertainties in model calibration. The multi-criteria approach deals with the uncertainty owing to the use of multiple model fitting criteria and the resulting trade-off in model performance. In our study, the observed river discharge data used in SWAT and HSPF model calibration were collected from the three gauging stations at the upper, middle, and lower main stem of the Illinois River. Instead of aggregating the measure of goodness-of-fit for three stations, the multi-criteria

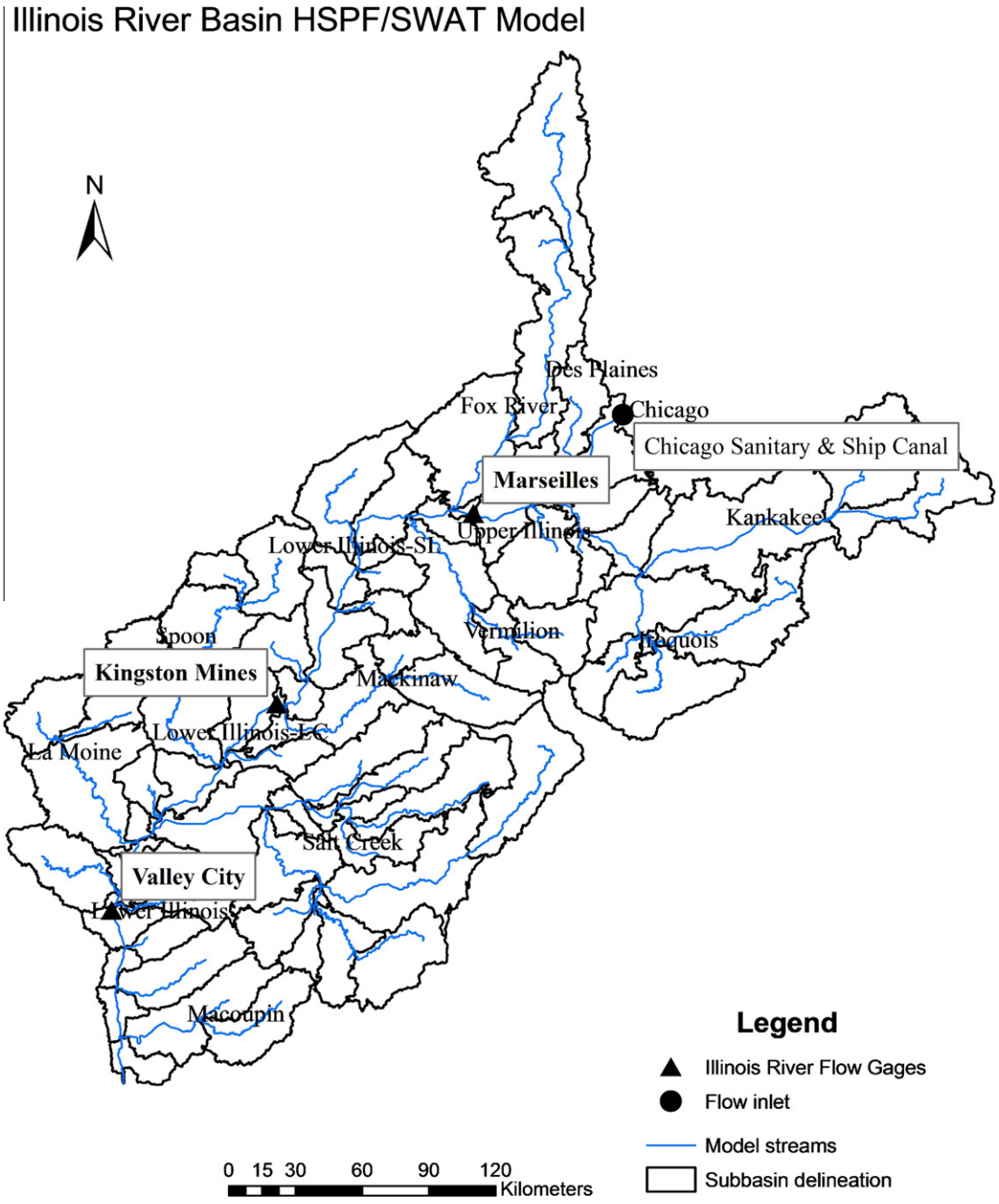

Fig. 1. The Illinois River Basin, the United States.