Hydrological modeling for flow-ecology science in the Southeastern U.S.

FINAL PROJECT MEMORANDUM

1. ADMINISTRATIVE:

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Project title: Hydrological modeling for flow-ecology science in the Southeastern U.S.: An inventory and evaluation of current efforts and knowledge gaps for global change impact studies addressing the SECSC FY2012 Annual Science Work Plan Ecohydrology Priority Science Need

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2. PUBLIC SUMMARY: Assessing the impact of flow alteration on aquatic ecosystems has been identified as a critical area of research nationally and in the Southeast U.S. This project aimed to address the Ecohydrology Priority Science Need of the SECSC FY2012 Annual Science Work Plan by developing an inventory and evaluation of current efforts and knowledge gaps in hydrological modeling for flow-ecology science in global change impact studies across the Southeast. To accomplish this goal, we completed a thorough synthesis and evaluation of hydrologic modeling efforts in the Southeast region (including all states of the Southeastern Association of Fish and Wildlife Agencies (SEAFWA) including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia) and Puerto Rico. Because this modeling synthesis was performed comprehensively and using a consistent methodology, it will provide landscape conservation cooperatives (LCCs) and other resource managers with a useful database of who is doing what, where, how, and how well in terms of hydrological modeling for global change impact studies across the Southeast region.

3. TECHNICAL SUMMARY: Hydrological models have the capacity to provide an estimate of the quantity of available water at areas of the country where USGS continuous recording gages are not installed. Additionally these models provide the baseline flow information necessary to develop the linkages between water availability and characteristics of streamflow that support dependent aquatic communities. This project evaluated and compared the potential causes of error associated with predicted streamflows from seven hydrologic models of varying complexity and calibration strategies in the Southeastern US. This was accomplished by computing and then comparing classical hydrologic model fit statistics (e.g., mean bias, coefficient of determination, root mean squared error, NSE), and understanding the bias in the prediction in these and a subset of ecologically relevant flow metrics (ERFM). Additionally, we compared streamflow predictions from a regional-scale hydrological model to those of several fine-scale SW models under a range of hypothetical climate change scenarios to determine the range of predicted streamflow responses to fixed climate perturbations. A pilot study was conducted using predicted streamflow and boosted regression trees to develop a set of predictive flow-ecology response models that assess the potential change in fish species richness in the North Carolina piedmont under several scenarios of water availability change. We acknowledge that this report provides a limited overview of the many tools and techniques available to support hydrologic modeling for flow-ecology science in the SEUS. However it is our hope that this rigorous approach to understanding differences in streamflow predictions among a subset of hydrological models currently in use in the Southeastern US and developing flow-ecology response models will provide water resource managers and stakeholders with an informed pathway for developing the capacity to link streamflow and ecological response and understand some of the limitations associated with these type of modeling efforts.

4. PURPOSE AND OBJECTIVES: The aim of this study was to 1) Inventory existing hydrologic modeling efforts in the Southeast region and Puerto Rico, 2) Evaluate and compare the performance of participating hydrologic models in predicting observed stream flows at multiple scales, 3) Demonstrate the feasibility of using regional and local scale models to identify unique areas of concern and understand fine scale hydrologic dynamics for climate change assessment, respectively, and 4) conduct a pilot study for regional-scale flow-ecological response modeling for global change impact assessment using the North Carolina Piedmont as an example.

5. ORGANIZATION AND APPROACH: The research objective activities of the project were conducted as follows: For objective 1, we researched modeling efforts in the region by contacting federal and state agencies, members of academia, and environmental consultants and created a database of models including model developer, intended purpose, model framework, spatial extent, spatial and temporal resolution, time period simulated, model inputs, model outputs (e.g., flow, water quality, ecosystem response), elements of global change represented (e.g., climate change, land use change, withdrawals/flow regulation), and validation procedure, criteria, and results. For objective 2, we contacted the developers of a subset of the model inventory and held a workshop where we will compared and contrasted both coarse-scale monthly models and fine-scale daily models, quantifying their ability to estimate observed flows over a common time period for selected basin(s) in the Southeast with ample record of observed flow. For objective 3, we compared streamflow predictions from WaSSI, a regional-scale model, to those of several of the fine-scale models that participated in the model comparison workshop under a range of hypothetical climate change scenarios to determine the range of predicted streamflow responses to fixed climate perturbations. Our working hypothesis was that similar predicted streamflow changes under climate change scenarios among regional and fine-scale models would provide evidence that these models could be used in combination to identify hotspots of concern and understand unique fine scale hydrologic dynamics. For objective 4, we developed a set of predictive flow-ecology response models that assess the potential change in fish species richness in the North Carolina piedmont under several scenarios of water availability change including streamflow withdrawals, climate change and land cover change.

6. PROJECT RESULTS: Median model fit statistics captured the magnitude, variability of observed flows and mean flow for the gages and time periods they simulated with median absolute bias in mean flow less than 6% across all models. The WATER IDE simulations tended to show high positive bias in many of the fit statistics. There was a tendency among some models to overestimate low flows. High flows were generally well-predicted, with median absolute bias in 90th percentile monthly flows less than 4.3% among the HSPF, PRMS, and SWAT models. Models results generally under-predicted the coefficient of variation of observed flows regardless of the time scale. For example, the median bias in the coefficient of variation in daily flows among daily time step models ranged from -2.6% (WaterFALL®) to -20.8% (PRMS-DAYMET). Winter (December-February) and early spring (March-May) flows were generally well predicted, but late spring, summer, and early fall flows (June-November) were often over-predicted. This likely reflects the over-prediction of low flows because the lowest flows on an annual basis typically occur during the summer and early fall months. Model performance was satisfactory or better according to the Moriasi et al. (2007) criteria for monthly NSE (>0.5) and bias in mean flow (<+/-25%) at most of the sites simulated by each model.

7. ANALYSIS AND FINDINGS: The intention of this model comparison study was not to suggest that the performance of any particular model is superior to that of the others. Rather, we were interested in understanding differences among hydrologic models and calibration strategies by quantifying and comparing the potential causes of error associated with model prediction and testing our hypotheses that, (1) in general, simple, regional-scale hydrologic models (e.g., MWBM, WaSSI) would have poorer predictive capacity and higher levels of uncertainty than the more complex fine-scale models (e.g., HSPF, PRMS, SWAT, WaterFALL®); and (2) models with higher levels of calibration would perform better than those that were less calibrated. In order accomplish these objectives; we summarized a subset of classical model fit statistics (e.g., NSE, RMSE, Bias) and ERFMs (e.g., MA41, MA25, DH20) for seven hydrologic models of varying calibration intensity across five study sites where modeling efforts overlapped with USGS continuous record gages.

8. CONCLUSIONS AND RECOMMENDATIONS: The primary objective of this study was to provide resource managers and environmental flow practitioners with some insight into the relative error in streamflow predictions among a subset of hydrologic models commonly used for water supply assessment, environmental flow studies, and climate change predictions. All of the models evaluated were developed by different agencies, for different purposes, with different input data sets, and, in general, were calibrated to different degrees using different objective functions. As a result, we could not separate the relative effect of model structure on prediction error from that of model calibration and modeler expertise. To fully evaluate the effect of model structure alone all models should be developed using the same inputs and calibrated to meet the same objective functions. However, our results do not indicate that any specific hydrologic model is superior to the others evaluated at all sites and for all measures of model performance, and do not support the hypothesis that simple, regional-scale models have less predictive power than more complex fine-scale models at a monthly time-step. Differences among model predictions for specific fit statistics or ERFMs are as likely to be related to differences in model calibration strategy as they are related to differences in model structure. As a result, we do not provide recommendations of one hydrologic model over another based on the results of this study. Instead we stress that it is incumbent upon resource managers, environmental flow practitioners, and policy makers to consider the expertise of the modeler, the applicability of a model to a particular resource problem, the context to which the model is being applied, the scale of interest and the important components of the flow regime that may be used for model calibration to minimize error across the targeted range of flows and thus, improve flow-ecology relations.

9. MANAGEMENT APPLICATIONS AND PRODUCTS: This study likely represents what may be the most rigorous evaluation of the use of hydrologic models for flow-ecology science compiled for the Southeastern U.S.. We, however, acknowledge that it may provide a limited overview of the many tools and techniques available. Despite these limitations, is our hope that this rigorous approach to understanding differences in streamflow predictions among a subset of hydrological models currently in use in the Southeastern US and developing flow-ecology response models will provide water resource managers and stakeholders with an informed pathway for developing the capacity to link streamflow and ecological response and understand some of the limitations associated with these type of modeling efforts.

10. OUTREACH: The model inventory contact list, in conjunction with the model comparison workshop, included 110 individuals from throughout the Southeast and Puerto Rico. Of these individuals, 22 agreed to be interviewed, including the participants of the synthesis workshop. Respondents were using multiple hydrologic models and were working throughout the Southeast and Puerto Rico. Additionally, we have linked responses to a spatially-enabled watershed database using ArcGIS. Future efforts should present this spatially-enabled database in a web mapping service. This type of application would display the results of our inventory of hydrologic models, facilitates further synthesis questionnaires, and link model metadata to a spatially-enabled watershed database. Although this application would be potentially valuable to the SECSC and appropriate target audiences, it is beyond the scope of the current project.