Scaling Up Watershed Model Parameters—Flow and Load Simulations of the Edisto River Basin

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ABSTRACT. The Edisto River is the longest and largest river system completely contained in South Carolina and is one of the longest free flowing blackwater rivers in the United States. The Edisto River basin also has fish-tissue mercury concentrations that are some of the highest recorded in the United States. As part of an effort by the U.S. Geological Survey to expand the understanding of relations among hydrologic, geochemical, and ecological processes that affect fish-tissue mercury concentrations within the Edisto River basin, analyses and simulations of the hydrology of the Edisto River basin were made with the topography-based hydrological model (TOPMODEL). The potential for scaling up a previous application of TOPMODEL for the McTier Creek watershed, which is a small headwater catchment to the Edisto River basin, was assessed. Scaling up was done in a step-wise process beginning with applying the calibration parameters, meteorological data, and topographic wetness index data from the McTier Creek TOPMODEL to the Edisto River TOPMODEL. Additional changes were made with subsequent simulations culminating in the best simulation, which included meteorological and topographic wetness index data from the Edisto River basin and updated calibration parameters for some of the TOPMODEL calibration parameters. Comparison of goodness-of-fit statistics between measured and simulated daily mean streamflow for the two models showed that with calibration, the Edisto River TOPMODEL produced slightly better results than the McTier Creek model, despite the significant difference in the drainage-area size at the outlet locations for the two models (30.7 and 2,725 square miles, respectively).

Along with the TOPMODEL hydrologic simulations, a visualization tool (the Edisto River Data Viewer) was developed to help assess trends and influencing variables in the stream ecosystem. Incorporated into the visualization tool were the water-quality load models TOPLOAD, TOPLOAD-H, and LOADEST. Because the focus of this investigation was on scaling up the models from McTier Creek, water-quality concentrations that were previously collected in the McTier Creek basin were used in the water-quality load models.

INTRODUCTION

Methylmercury (MeHg) contamination is the leading cause of fish consumption advisories in the United States, affecting 40 percent of lake area and 36 percent of river distance (U.S. Environmental Protection Agency, 2011). Over 4,700 water bodies in the United States are reported on State Clean Water Act Section 303(d) lists as being impaired due to mercury (U.S. Environmental Protection Agency, 2013). Mercury-specific fish consumption advisories affect more than half of South Carolina, including the entire Coastal Plain physiographic province within the State. Methylmercury is the primary form of mercury in fish (Bloom, 1992). Exposure to methylmercury may cause immune system suppression, neurodevelopmental delays, and compromised cardiovascular health in humans (Mergler and others, 2007), as well as behavioral, neurochemical, hormonal, and reproductive changes in wildlife (Scheuhammer and others, 2007; 2012).

In light of the critical role of hydrology as a driver of methylmercury concentrations within the stream aquatic habitats of the Edisto River Basin in particular and the Coastal Plain in general, numerical tools that reliably simulate the direction, timing, and quantity of water transport contribute substantially to better understanding and management of mercury risk across multiple scales. Previous reports describe the development and application of a hydrologic model (TOPMODEL) for McTier Creek (Feaster and others, 2010, 2012), a small headwater catchment that covers about 38 square miles (mi^2) of the Edisto River Basin. A recent intra-basin mercury assessment conducted in the Edisto River Basin of South Carolina indicates that results from small basin studies provide a reasonable foundation for development of orders-of-magnitude upscaled conceptual or numerical models for application at large-basin and regional scales within the Edisto River Basin and within the Coastal Plain (Bradley and others, 2013).

Building upon the application of TOPMODEL to McTier Creek (Feaster and others, 2010, 2012), an investigation was undertaken to scale up TOPMODEL to the larger Edisto River Basin (Feaster and others, 2014). Hydrologic simulations from TOPMODEL were then applied to TOPLOAD and TOPLOAD–H to evaluate water-quality loads associated with water-quality constituents such as mercury. Similar to the McTier Creek watershed investigation (Benedict and others, 2012; Feaster and others, 2010; Golden and others, 2012), the hydrologic and water-quality output from such simulations can be used to provide a framework for an improved understanding of the spatial and temporal variability relation of mercury and hydrology in the larger Coastal Plain basin.

PROJECT DESCRIPTION

The Edisto River is the longest and largest river system completely contained in South Carolina and is one of the longest free-flowing black-water rivers in the United States (South Carolina Department of Natural Resources, 2009). The basin is located in south-central South Carolina and includes parts of the upper and lower Coastal Plain regions (fig. 1; South Carolina Department of Health and Environmental Control, 2012). The total basin encompasses about 3,150 mi^2 and is drained by four major rivers: North Fork Edisto River, South Fork Edisto River, Edisto River (main stem), and Four Hole Swamp.

This paper describes results from the assessment of upscaling the McTier Creek TOPMODEL (Feaster and others, 2010, 2012) to the larger Edisto River Basin with the downstream boundary for this study being located at USGS streamflow gaging station (station) 02175000, Edisto River near Givhans, SC (Feaster and others, 2014). In addition, it gives a brief overview of the Edisto River Data Viewer, which is a spreadsheet application that provides a means to visualize selected data trends using graphs that display (1) time-series plots and scatterplots of selected hydrologic and water-quality data, (2) seasonal trends associated with selected hydrologic and water-quality data, and (3) comparison plots of selected model simulations.

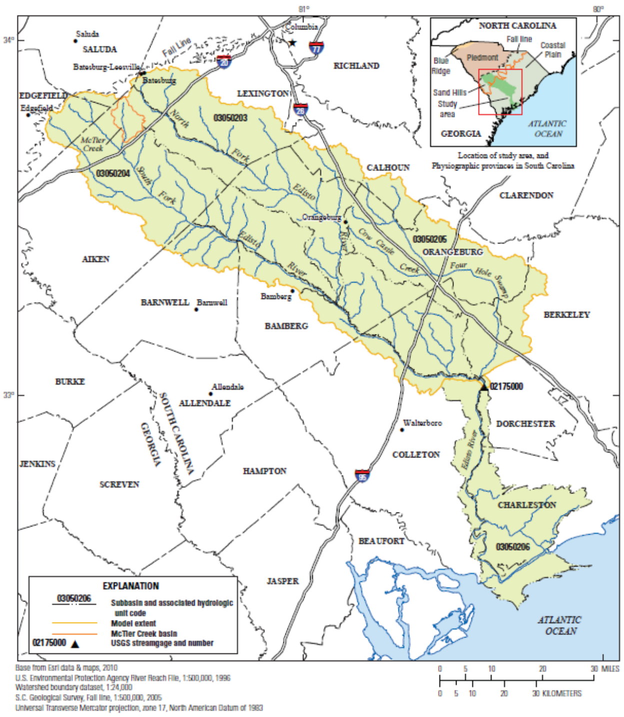

Figure 1. Edisto River Basin and U.S. Geological Survey streamflow gaging station 02175000, Edisto River near Givhans, SC.

TOPMODEL

TOPMODEL (a topography-based hydrological model) is a physically based watershed model that simulates streamflow based on the variable-source-area concept of streamflow generation (Beven and Kirby, 1979). TOPMODEL systematically accounts for water as it enters the watershed as precipitation until it leaves the watershed through evapotranspiration, by direct withdrawal, or as streamflow (fig. 2).

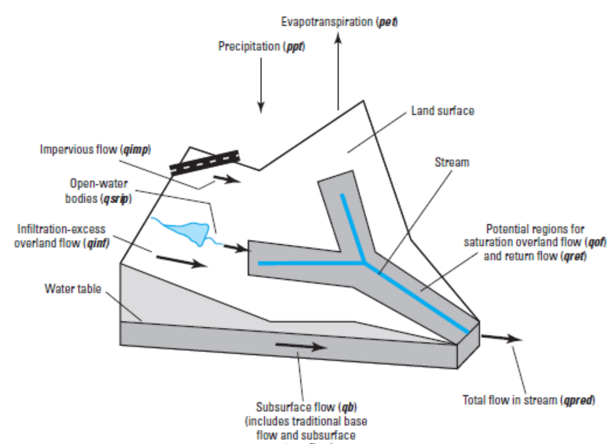

Figure 2. Definitions of selected water-source variables from TOPMODEL (modified from Wolock, 1993).

Hydrologic simulations in TOPMODEL require the following types of inputs: (1) a time series of meteorological data (total daily rainfall and average daily air temperature), (2) a topographic wetness index distribution (TWI), and (3) model parameters, including measured watershed characteristics and calibrated parameters. Streamflow data are not required for the model simulation but are used to assess how well the simulations capture the characteristics of the measured streamflow data. Streamflow assessments for this study were made by using data from station 02175000 (fig. 1).

STREAMFLOW SIMULATION RESULTS

The streamflow simulations for the Edisto River were done in a step-wise manner, starting with applying calibrated TOPMODEL parameters, TWI data, and meteorological data from the McTier Creek model (Feaster and others, 2010, 2012) to the Edisto River model. Additional data from the Edisto River were then applied, and lastly, the parameter estimation program (PEST) was used to help calibrate model parameters for the Edisto River model (Doherty, 2005). PEST, which also was used to calibrate the McTier Creek TOPMODEL, is a nonlinear parameter estimator that adjusts model parameters until the fit between simulated streamflow estimates and observed streamflow are optimized by using a weighted least-squares scheme. If initial simulations using PEST indicated no change in a parameter from the value used in the McTier Creek TOPMODEL, the value was held constant in subsequent PEST runs.

The Edisto River TOPMODEL simulations were assessed using observed daily mean streamflow at station 0217500 for the period from June 13, 2007, to September 30, 2009, which was the same simulation period used at the outlet location for the McTier Creek TOPMODEL. Next-Generation Radar (NEXRAD) stage IV precipitation data were found to improve the streamflow simulations as compared to using weighted observed precipitation data from National Weather Service cooperative meteorological stations located in and around the Edisto River Basin that are part of the Global Historical Climatology Network (GHCN). It was surmised that this outcome was due to the NEXRAD rainfall data being generated from a much finer and consistent grid as compared to those used for the inverse-distance and Thiessen polygon weighting methods used with the GHCN data.

Of the calibrated parameters for the McTier Creek TOPMODEL, only the scaling parameter, *m*, which describes the change of the exponential decay function for transmissivity with depth as a function of surface transmissivity (Wang and others, 2006), had to be adjusted to obtain the best-fit model for the Edisto River (fig. 3). The goodness-of-fit statistics for the calibrated Edisto River TOPMODEL were slightly better than those for the McTier Creek TOPMODEL, even though there is a substantial difference in the basin sizes (30.7 and 2,725 mi^2, respectively). For the Edisto River model with the best goodness-of-fit statistics, the Nash-Sutcliffe efficiency coefficient (*NSE*) was 0.78, the Pearson's *r* was 0.89, and the percent bias (*PBIAS*) was –0.7 percent. For the McTier Creek model, the *NSE* was 0.67, *r* was 0.82, and *PBIAS* was –0.87.

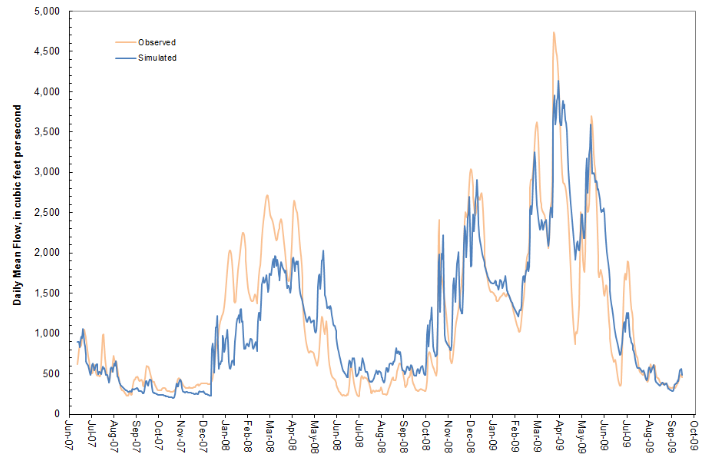

Figure 3. Simulated and observed daily mean flow at station 02175000, Edisto River near Givhans, SC, for June 13, 2007, to September 30, 2009.

EDISTO RIVER DATA VIEWER

Using the same digital platform developed for the McTier Creek Data Viewer, a tool developed to analyze and visualize the abundant hydrologic and water-quality data associated with the McTier Creek watershed mercury investigation, the Edisto River Data Viewer was developed for this investigation. The Edisto River Data Viewer consists of a set of Microsoft Excel spreadsheets that incorporate selected measured and modeled data at station 02175000 for the same period used in the McTier Creek investigation (June 2007 to August 2009). Applications within the Edisto River Data Viewer provide a means for visualizing selected data trends using graphs that display (1) time-series plots and scatterplots of selected hydrologic and water-quality data, (2) seasonal trends associated with selected water-quality constituents, and (3) comparison plots of selected model simulations. As was done for McTier Creek, TOPLOAD, TOPLOAD–H, and the Load Estimator (LOADEST) water-quality load models also were incorporated into the Edisto River Data Viewer. After successfully calibrating the Edisto River TOPMODEL, streamflow simulations for the Edisto River Basin were used with water-quality concentration data from McTier Creek to evaluate loads for selected water-quality constituents and the various flow components available from TOPMODEL utilizing the water-quality load models in the Edisto River Data Viewer. Feaster and others (2014) provide details of those simulations.

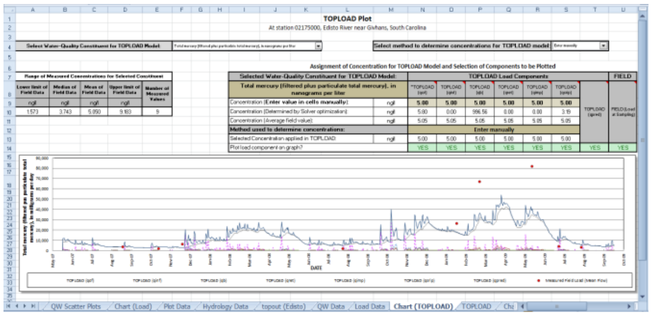

Figure 4. Screen capture from the Edisto River Data Viewer TOPLOAD worksheet showing simulated and measured total mercury loads for the Edisto River.

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