

# THE APPLICATION OF TOPMODEL TO ASSESS MERCURY FLUXES IN THE MCTIER CREEK WATERSHED

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**Abstract.** The watershed model TOPMODEL (a TOPography based hydrological MODEL) is being applied to the McTier Creek watershed in the Edisto River Basin of South Carolina to assess the hydrologic controls on the transport of mercury species between uplands/hillslopes, riparian wetlands, and stream channels. TOPMODEL is a physically based watershed model that simulates the variable-source-area concept of streamflow generation. Preliminary applications of the results from TOPMODEL have been used to show hydrologic conditions when the riparian wetlands are connected to the channels in the watershed. Understanding the timing and magnitude of these connections may provide insight into potential mobilization of methylmercury from the wetlands to the receiving streams. Additional analyses using these saturated-area concepts are planned as final model calibrations are completed.

## INTRODUCTION

Methylmercury (MeHg) is produced from inorganic mercury by methylation, which is a complex process that is controlled by certain bacteria and enhanced by chemical and environmental variables, which include the presence of organic matter and oxygen. MeHg also is a form of mercury (Hg) that is easily accumulated in the tissues of organisms and is highly toxic to the human nervous system (Brigham and others, 2003). A nationwide investigation of MeHg in fish tissues showed that samples collected in the Edisto River Basin were among the highest in the Nation with respect to methylation efficiency (the ratio of MeHg to total mercury (Hgtot)) (Hughes and others, 2000). In 2007, the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) developed and implemented a quantitative approach to assess water-borne fluxes or loads of Hgtot and MeHg as well as Hg bioavailability and bioaccumulation in the McTier Creek watershed, which is a small head-

water basin in the Edisto River Basin, South Carolina (fig. 1). Bioavailability refers to the fraction of the chemical in the environment that is available for biological action and bioaccumulation refers to a process by which a concentration of a substance increases as it moves up the food chain. An important part of this process is understanding how the MeHg is delivered from source areas to the stream system.



**Figure 1. McTier Creek watershed, South Carolina.**

## STUDY AREA

McTier Creek is a small headwater stream located in the Edisto River Basin and drains about 30 square miles and contains about 77 percent forest, 14 percent agriculture, 8 percent perennial wetland, and about 1 percent open water (fig. 1). Headwaters are typically defined as the upper reaches of a basin or watershed, and thus contain smaller streams and tributaries to larger water bodies. McTier Creek lies within the upper part of the Coastal Plain known as the Sand Hills. This part of the Coastal Plain also is referred to as the inner or upper Coastal Plain (Blokhman, 1976). The McTier Creek watershed begins near the Fall Line, which is the name given to the boundary between the Piedmont and upper Coastal Plain physiographic provinces. In general, this boundary is characterized by a series of rapids or falls where the streams tumble off the more resistant rocks of the Piedmont into the deeper valleys worn in the softer sandy sediments of the Coastal Plain (Cooke, 1936). Commonly, the headwaters of basins located just below the Fall Line display characteristics similar to Piedmont streams with transitions to Coastal Plain characteristics beyond the headwaters. Figure 2 shows an example of rock outcrops in the upper part of the McTier Creek watershed that transition to Coastal Plain characteristics, as shown in the hillside cross section of figure 3. The survey rod shown in figure 3 is extended approximately 20 feet and provides an indication of the depths of sand deposits that can be found in the Sand Hills.

A substantial portion of the McTier Creek landscape is dominated by uplands and hillslopes, which provide a favorable environment for the transport of constituents, such as atmospherically deposited Hg, by surface-water runoff and shallow ground-water flow. Likewise, the predominantly saturated and seasonally inundated soils and sediments of the riparian stream borders favor the onset of reducing conditions and efficient Hg methylation in the shallow subsurface environment. Finally, the dissolved concentration of MeHg in the stream channel water column may be attributable in large part to the efficiency of MeHg transport from out-of-channel wetland environments to the stream channel by surface-water floods and (or) shallow ground-water flow. There are two USGS streamflow gaging stations located on McTier Creek (02172300, McTier Creek near Monetta, S.C., and 02172305, McTier Creek near New Holland, S.C.) that provide an important resource for assessing and modeling hydrologic conditions within the basin (fig. 1). The basin characteristics for McTier Creek and the USGS streamflow gaging stations provide favorable conditions for assessing various scenarios for the production and delivery of MeHg to the Edisto River.



**Figure 2. McTier Creek near the upper part of the basin displaying stream characteristics similar to the Piedmont.**



**Figure 3. Cross section of hill side approximately 0.2 mile from the location shown in figure 2 displaying characteristics typically of the Sand Hills.**

## APPROACH

A conceptual model for the transformation of Hg to MeHg within the headwaters of the Edisto River Basin and subsequent transport to the river includes (1) the atmospheric deposition of Hg on the headwaters of the Edisto River Basin; (2) the methylation of the Hg promoted by the conditions in the riparian wetlands; and (3) the transport of the MeHg in the riparian wetlands to the river by surface-water floods and (or) shallow ground-water flow. This conceptual model indicates that significant insight into the controls of MeHg production and transport in an Hg-impacted stream system, such as the Edisto River Basin, can be gained by detailed monitoring and assessment, and accurate modeling of the hydrology of the watershed. The characteristics of the McTier Creek watershed and its association with the Hg-impacted Edisto River Basin provide an opportunity for applying and testing these conceptualizations.

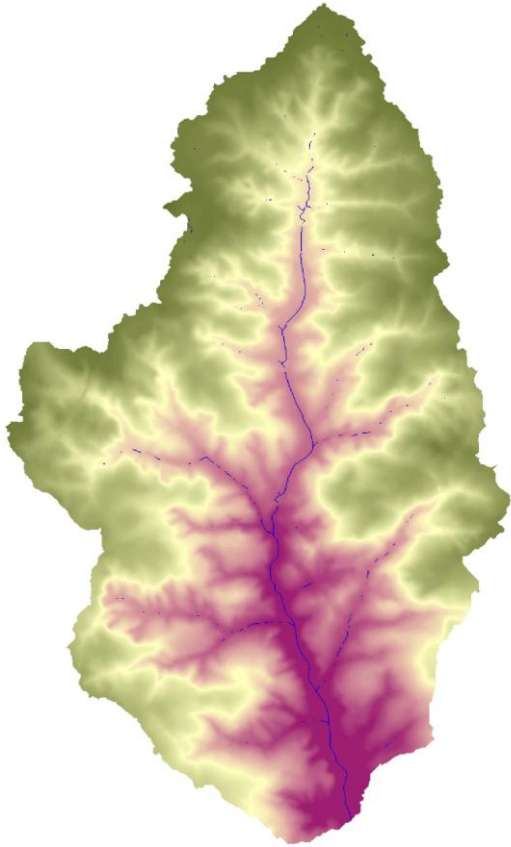
To test the viability of the conceptual model, it is important to understand the hydrologic conditions of the McTier Creek basin. To assess the hydrologic controls on the transport of Hg species between uplands/hillslopes, riparian wetlands, and stream channels in the McTier Creek watershed, the watershed model TOPMODEL (a TOPography based hydrological MODEL) is being applied to the system. TOPMODEL is a physically based watershed model that simulates the variable-source-area concept of streamflow generation (Beven, 1996; Wolock, 1993). TOPMODEL utilizes coverages defining soil and topographic properties. In addition to streamflow, model predictions include estimates of overland and subsurface flow, and an estimate of the spatial pattern of the depth to the water table in the watershed. TOPMODEL is a relatively simple model that has been used to describe stream runoff and its sources on the landscape in upland watersheds, and is an appropriate tool for exploring runoff in the study watershed. TOPMODEL inputs consist of topographic parameters, soils specifications, watershed latitude, and time series of precipitation and air temperature. Model outputs include overland flow, subsurface flow, and saturation deficit (depth to water table).

An important process in the proposed conceptualization of the production and delivery of MeHg to the Edisto River is the methylation of Hg in the saturated riparian wetlands. Therefore, it is important to understand the frequency and extent with which these areas become saturated. TOPMODEL can simulate this process using the variable-source-area

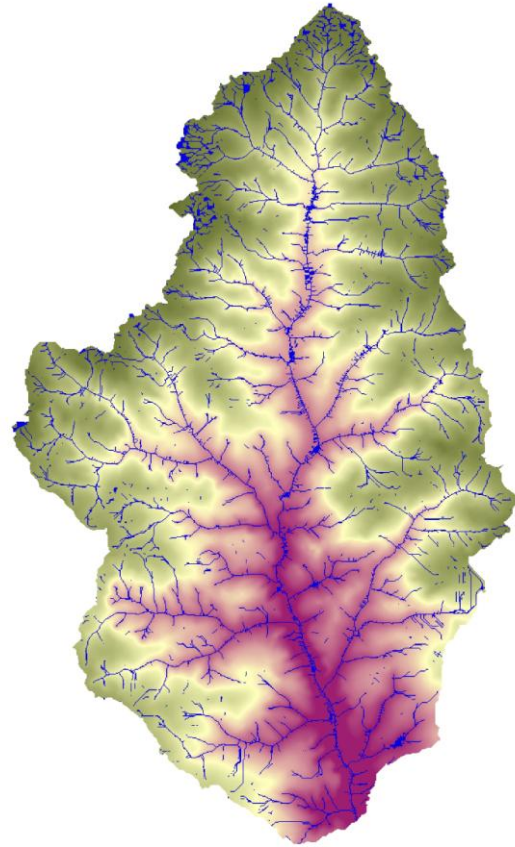
concept. The variable-source-area concept states that streamflow during precipitation events is generated on saturated surface areas called "source areas," which occur in places where the water table rises to the land surface (Wolock, 1993). The rise in the water table occurs because of infiltration of precipitation into the soil down to the saturated subsurface zone, and the subsequent downslope movement of water in the saturated subsurface zone. Saturated land-surface areas commonly develop near existing stream channels and expand as more water enters the subsurface through infiltration and moves downslope as saturated subsurface flow. Variable-source-area flow occurs where infiltration rates are greater than precipitation rates.

## PRELIMINARY RESULTS AND DISCUSSION

Preliminary applications of TOPMODEL to the McTier Creek basin have used the computed saturated areas generated by the model in a temporal analysis of animations of the spatial distribution of soil saturation (figs. 4a and 4b). The saturated-area values from TOPMODEL show hydrologic conditions when the riparian wetlands are connected to the channels in the watershed. Figure 4a shows an example of a low-flow condition for which the daily mean flow was approximately 5 cubic feet per second ( $\text{ft}^3/\text{s}$ ) on March 10, 2002. The blue areas along the main channel and tributary stems show areas of saturation. Figure 4b shows an example of a high-flow condition on March 22, 2003, for which the daily mean flow was approximately 73  $\text{ft}^3/\text{s}$ . Figure 5 shows the relation between daily mean streamflow and fraction of saturated area at the outlet of the basin area for which the data are being obtained to map the saturated area for the entire watershed. As can be seen in figure 5, although the total percent of the watershed that was saturated during the high-flow event was relatively small, the increase in the total saturated area from the low-flow condition was an order of magnitude larger (approximately 2 percent and 0.2 percent, respectively). Understanding the timing, frequency, and magnitude of these connections may provide valuable insight into potential mobilization of MeHg from the wetlands to the receiving streams. Additional analyses using these saturated-area concepts and relations between the various flow components generated by TOPMODEL and Hg samples being collected in the McTier Creek basin are planned as final model calibrations are completed.

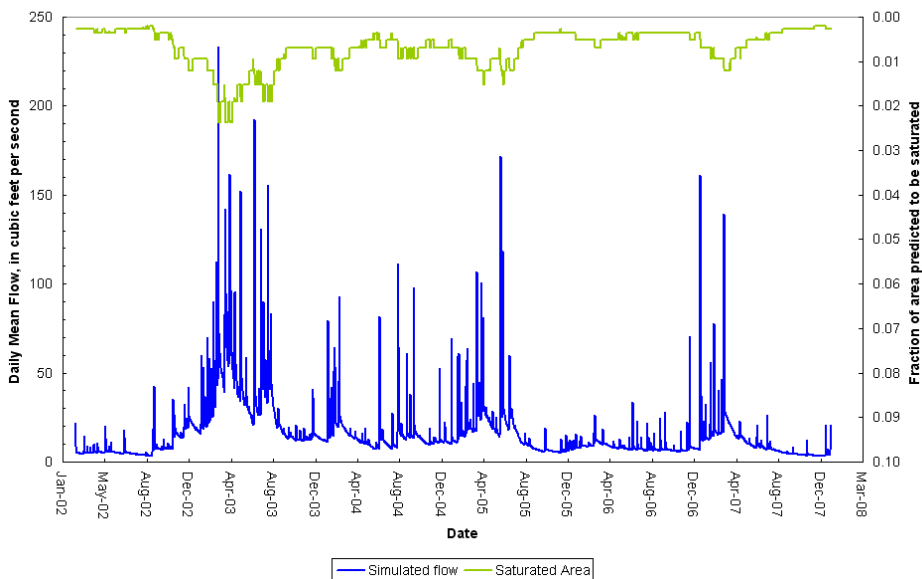


**Figure 4a. McTier Creek basin saturated areas under low-flow conditions (approximately 5 cubic feet per second) on March 10, 2002.**



**Figure 4b. McTier Creek basin saturated areas under high-flow conditions (approximately 73 cubic feet per second) on March 22, 2003.**

Station 02172300, McTier Creek near Monetta, S.C.



**Figure 5. Simulated streamflow and saturated area at McTier Creek near Monetta, S.C.**

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