

Development of a Mercury Load Model for McTier Creek, South Carolina Using TOPMODEL

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Introduction

The bioaccumulation of mercury in the food chain of stream ecosystems is a public health concern in many parts of the United States (Brigham and others, 2003) and is one of the leading causes for impairment of the Nation's water bodies (U.S. Environmental Protection Agency, 2008; fig. 1). The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) has been conducting field investigations of mercury with the goal of advancing the state-of-the-knowledge and developing tools to assist in managing and mitigating the adverse impacts of mercury in stream ecosystems. One of these studies is the recent (2007-2009) USGS NAWQA investigation of mercury in McTier Creek (Bradley and others, 2010; 2011). McTier Creek is a small watershed located in Aiken County, South Carolina and forms part of the headwaters for the Edisto River basin (fig. 2), which is noted for having some of the highest measured fish-tissue mercury concentrations in the United States (Hughes and others, 2000; Brumbaugh and others, 2001).

The investigation included the collection of hydrologic, biologic, and water-quality data as well as the development of a number of hydrologic and water-quality models to assess the fate and transport of mercury. One modeling effort involved the development of a simple water-quality load model that utilized a mass-balance equation in conjunction with hydrologic simulations from the topography-based hydrological model. A brief description of the development of this simple load model and a sample simulation in the McTier Creek basin are presented.

TOPMODEL

To understand the in-stream water quality of an ecosystem, it is important to assess the various surface and subsurface flow components that contribute to in-stream flow. A useful model for assessing the surface and subsurface flows within a watershed is TOPMODEL (Wolock, 1993). TOPMODEL is a physically based, semi-distributed watershed model that simulates hydrologic fluxes by systematically accounting for water as it enters the watershed as precipitation (*ppt*) until it leaves the watershed through evapotranspiration (*pet*) and streamflow (*qpred*) (fig. 3). In addition to the simulation of total streamflow (*qpred*), TOPMODEL also simulates the surface and subsurface flow components that contribute to that flow (fig. 3).

The surface flow components consist of:

- infiltration-excess overland flow (*qinf*),
- saturation overland flow (*qof*),
- impervious area overland flow (*qimp*), and
- direct rainfall on water bodies (*qsrip*).

The subsurface flow components consist of:

- return flow (*qret*), which is flow associated with the upper portion of the saturated soil and generally exfiltrates in the riparian areas near the stream, and
- base flow (*qb*), which is flow associated with the lower portion of the saturated soil and generally exfiltrates directly into the stream channel.

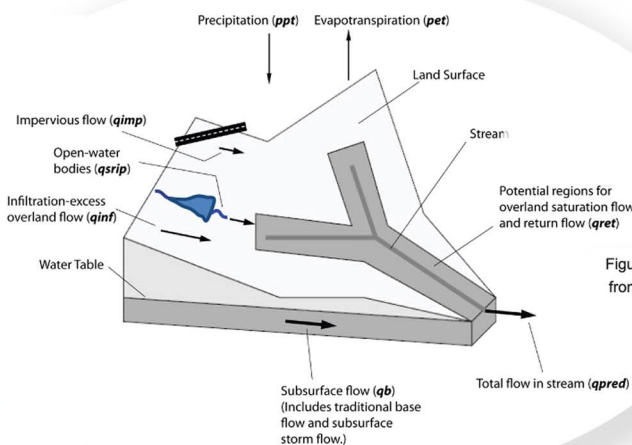


Figure 3. Definition of selected water-source variables from TOPMODEL (modified from Wolock, 1993)

TOPMODEL simulates the daily average flow for each component.

An example of the simulated flow components for McTier Creek is shown in figure 4.

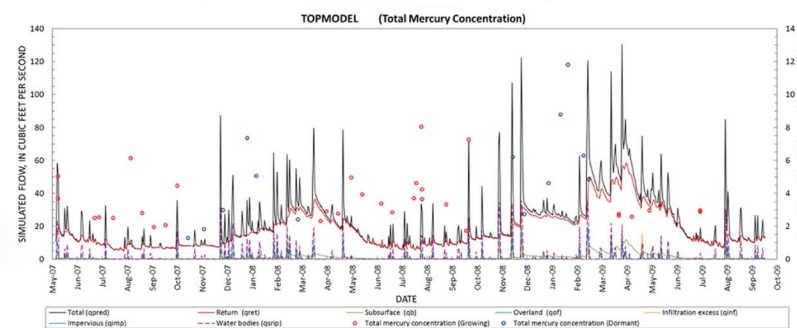


Figure 4. Simulated daily mean flows generated by TOPMODEL (Feaster and others, 2010) and in-stream measurements of total mercury concentration during dormant and growing seasons, May 2007–October 2009 at streamflow-gaging station 02172305, McTier Creek near New Holland, South Carolina.

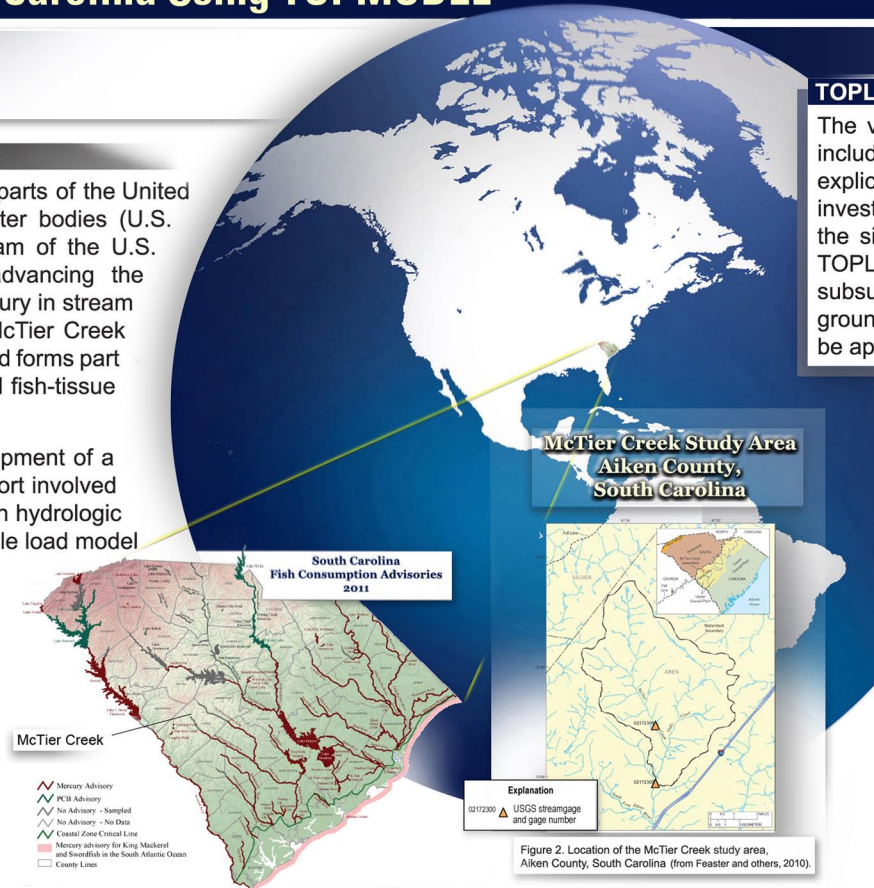


Figure 2. Location of the McTier Creek study area, Aiken County, South Carolina (from Feaster and others, 2010).

Figure 1. Map showing 2011 fish consumption advisories for South Carolina waters with mercury advisories highlighted in red (from South Carolina Department of Health and Environmental Control, accessed June 7, 2011, at <http://www.scdhec.gov/environment/water/fish/docs/map.pdf>).

TOPLOAD and TOPLOAD-H

The version of TOPMODEL applied to the McTier Creek investigation (Feaster and others, 2010) does not include a mass-balance algorithm for evaluating water-quality loads. However, such an algorithm can be applied explicitly (by a spreadsheet) to TOPMODEL simulations resulting in a water-quality load model. In this investigation, several variants of this load model were developed including one, called TOPLOAD, which utilized the simulated surface and subsurface flow components taken directly from TOPMODEL. A second variant, TOPLOAD-H, added a groundwater partitioning algorithm (Hornberger and others, 1994) to the summed subsurface flow components of TOPMODEL (summation of *qret* and *qb*), thereby providing for multiple groundwater flow components. Although these models were developed to assess mercury loads, they also can be applied to other water quality constituents.

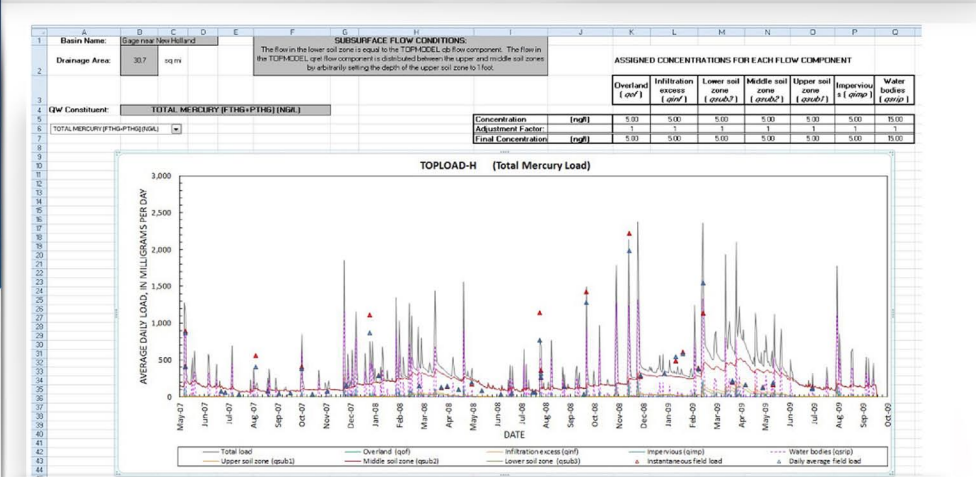


Figure 5. Screen capture from the TOPLOAD-H worksheet showing input table for assigned concentrations to TOPMODEL flow components along with simulated daily mean loads for total mercury at streamflow-gaging station 02172305, McTier Creek near New Holland, South Carolina compared with discrete field observations for the total mercury load.

TOPLOAD is a subset of the more flexible TOPLOAD-H model, with respect to the number of subsurface flow components. The general equation for both TOPLOAD and TOPLOAD-H is as follows:

$$LOAD = Q_{sub1} C_{sub1} + Q_{sub2} C_{sub2} \dots + Q_{subn} C_{subn} + Q_{qinf} C_{qinf} + Q_{qimp} C_{qimp} + Q_{qsrip} C_{qsrip} + Q_{qof} C_{qof} \quad (1)$$

where, *LOAD* represents the simulated daily average watershed load associated with a given water-quality constituent; $Q_{sub1}, Q_{sub2}, \dots, Q_{subn}$ represent the TOPMODEL subsurface flow as distributed across the number of soil zones, *n* (Note: For TOPLOAD, *n* is equal to 2 and the subsurface flows reduce to *Qret* and *Qb* as associated with the respective TOPMODEL subsurface flow components); $Q_{qinf}, Q_{qimp}, Q_{qsrip}, Q_{qof}$ represent the flows associated with the respective TOPMODEL surface flow components; and $C_{sub1}, C_{sub2}, \dots, C_{subn}, C_{qinf}, C_{qimp}, C_{qsrip}, C_{qof}$ represent the concentration of the given water-quality constituent associated with the respective flow component. TOPMODEL output data are imported into a spreadsheet, concentrations for the constituent of interest are assigned to each flow component manually or by a parameter estimation routine (fig. 5), and equation 1 is applied to these data within the spreadsheet.

Results

The simulated daily average loads for total mercury using TOPLOAD-H at the USGS streamflow-gaging station 02172305, McTier Creek near New Holland, South Carolina are shown in figure 5 for the period of May 2007 through October 2009. Loads in figure 5 are based on the flow components simulated from TOPMODEL (fig. 4). A comparison of the simulated loads with measured loads, associated with discrete field measurements (fig. 5), indicates that TOPLOAD-H provides reasonable estimates of daily average loads.

Discussion

Results from this investigation indicate that the TOPLOAD and TOPLOAD-H models, developed from TOPMODEL flow simulations, can be useful tools for understanding water-quality loads in stream ecosystems. In particular, these models provide a means of assessing the relative influence of selected flow components (surface and subsurface) on in-stream water quality and can be used to test hypotheses regarding transport processes of a given water-quality constituent. Although TOPLOAD and TOPLOAD-H were developed to evaluate loads associated with mercury, these models also can be used to assess loads for other water-quality constituents. Additional details regarding the development of TOPLOAD and TOPLOAD-H can be found in Benedict and others (in preparation).

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