# WATERSHED MODEL SENSITIVITY TO BACTERIA PARAMETERS

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**Abstract.** Watershed-scale models can be used to determine the pollutant daily load in TMDL streams, or to test the effect of different scenarios for reducing bacterial load. HSPF (Hydrological Simulation Program – FORTRAN ) is a watershed-scale model distributed as part of the EPA BASINS system. EPA has also developed a Bacterial Indicator Tool for calculating the effect of livestock and septic systems on the bacterial parameters required by HSPF. We used HSPF and the Bacterial Indicator Tool to predict stream flow and FC concentrations in the Little River watershed of the Upper Oconee River basin and test for model sensitivity to bacteria parameters. We calibrated flow and FC concentrations using data from a USGS gaging station at the Highway 16 crossing near Eatonton, GA. The bacteria samples were collected during the period 1990 to 1994. We tested the sensitivity of the model predictions of FC to bacteria parameters by doubling the values of the parameters and calculating the root mean square change in predicted FC concentration. The most sensitive parameters were (in order of decreasing sensitivity): number of beef cattle, number of dairy cattle, time cattle spend in stream, and in-stream first-order decay rate.

## INTRODUCTION

More than 600 stream, river, and lake segments are listed as impaired on the Georgia Section 303(d) list. The most common reason for listing is excessive levels of fecal coliform (FC) bacteria (USEPA, 2003b). FC is used as an indicator of pathogenic bacteria and viruses and the state water quality standard is a geometric mean of no more than 200 coliforms per 100 mL during the period May through October and no more than 1000 coliforms per 100 mL during the period November through April.

For the streams on the 303(d) list, a Total Maximum Daily Load (TMDL) must be established under the Clean Water Act administered by the U.S. EPA (USEPA, 1991). For streams listed because they do not meet the FC water quality standard, the TMDL of FC from all point and nonpoint sources in the watershed must be estimated that will keep the maximum FC concentration below the standard under “critical conditions” of weather and stream flow (USEPA, 1991). For streams dominated by nonpoint sources, maximum FC concentrations usually occur during storms so the critical conditions are assumed to occur during storms. Because FC samples must be refrigerated and laboratory analysis must be initiated within 24 hours after the sample is collected, most FC samples are collected manually and taken directly to a lab. As a result, there are few FC samples taken during storm flow when concentrations are likely to reach a maximum in watersheds dominated by nonpoint sources.

Watershed-scale computer models have been developed to predict stream flow and pollutant concentrations in streams. When these models are properly calibrated, they can be used to fill the gaps between the observed FC concentrations on an impaired stream and reveal the maximum FC concentrations during storms. They can also be used to determine what combinations of point and nonpoint source daily loads will maintain FC concentrations below the water quality standard (ie., the TMDL).

To facilitate the development of TMDLs, the U.S. EPA has made available a suite of watershed-scale computer models, databases, and Geographic Information System (GIS) data layers under the Better Assessment Science Integrating Nonpoint Sources (BASINS) system (USEPA, 2003a). One of the models in BASINS is the Hydrological Simulation Program – FORTRAN (HSPF) developed by Bicknell et al. (2001). EPA has also developed a Bacteria Indicator Tool for calculating the effect of livestock, wildlife, and septic systems on bacterial parameters that are required in HSPF (USEPA, 2000). It's important to know to which input parameters the model prediction is most sensitive, because these are the parameters that need to be known most precisely.

In a recent study conducted at the Central Georgia Research Station within the Little River watershed, we measured the time that beef cattle spent in streams using globalpositioning system sensors (Matthews et al.., 2003).

In this study, we used the Bacterial Indicator Tool and HSPF to simulate stream flow and FC concentrations in the Little River which on the list for a FC TMDL. Our objective was to test the model for sensitivity to bacteria parameters, including the time cattle spent in streams.

## METHODS

The Little River is a tributary of the Upper Oconee River in Northeast Georgia. We used the USGS gage station (02220900) at the highway at the Highway 16 crossing near Eatonton, GA to define our watershed. Thirty six bacteria samples were collected at this site during the period 1990 to 1994 and daily stream flow data was available for the period 1977 to 2001. The contributing watershed area at this point is 262 square miles.

We used the automatic watershed delineation feature in BASINS to divide the watershed into 31 subwatersheds. Landuse was taken from the Multiresolution Land Characteristics (MRLC) data layer and the areas for different landuses are given in Table 1. The Little River watershed lies predominately in Morgan County. We used the livestock numbers from the 1996 agricultural census (GASS, 1997) to estimate the number of livestock in the Little River watershed by assuming a similar density of animal to total land area in the watershed and county (Table 2).

The Bacteria Indicator Tool uses livestock numbers and landuse areas to estimate several parameters that are required by HSPF. To estimate bacteria loading from runoff, HSPF uses build-up and wash-off curves. Two parameters are required by theses curves: the rate of FC accumulation (ACQOP) and the upper limit of FC surface storage (SQOLIM). The Bacteria Indicator Tool uses information from the scientific literature on concentrations of FC in various types of animal manures, rates of production of animal manure, and bacteria die-off rates to estimate these parameters. The only type of wildlife considered by the Bacterial Indicator Tool is deer and it assumes a density of 5 deer per square mile on forest and agricultural land. To estimate bacteria loading from cattle that have access to streams, an estimate is made of the FC load in counts per hour and the waste load in cfs based on an assumed percentage of time that cattle spend in the stream. To estimate bacteria loading from failed septic systems, and estimate of the bacteria and waste load is also made based on an assumed failure rate for septic systems. We assumed that all of the households in the Little River watershed were on septic systems and estimated the number of people and households in the watershed by assuming the population density was the same as that given in the U.S. Census 2001 estimate for Morgan County (U.S. Census Bureau, 2003).

**Table 1. Landuse areas for the Little River watershed from MRLC data**

| Landuse | Area (acres) |
|---|---|
| Forest | 117,920 |
| Pasture | 29,828 |
| Crop Land | 14,099 |
| Urban | 5,442 |
| Wetlands | 3,234 |
| Water | 859 |
| Barren | 254 |
| Total | 171,638 |

**Table 2. Livestock numbers estimated for the Little River watershed from agricultural census data**

| Livestock | Number |
|---|---|
| Beef cattle | 19,740 |
| Dairy cows | 5,413 |
| Swine | 1,676 |
| Chickens | 190,542 |

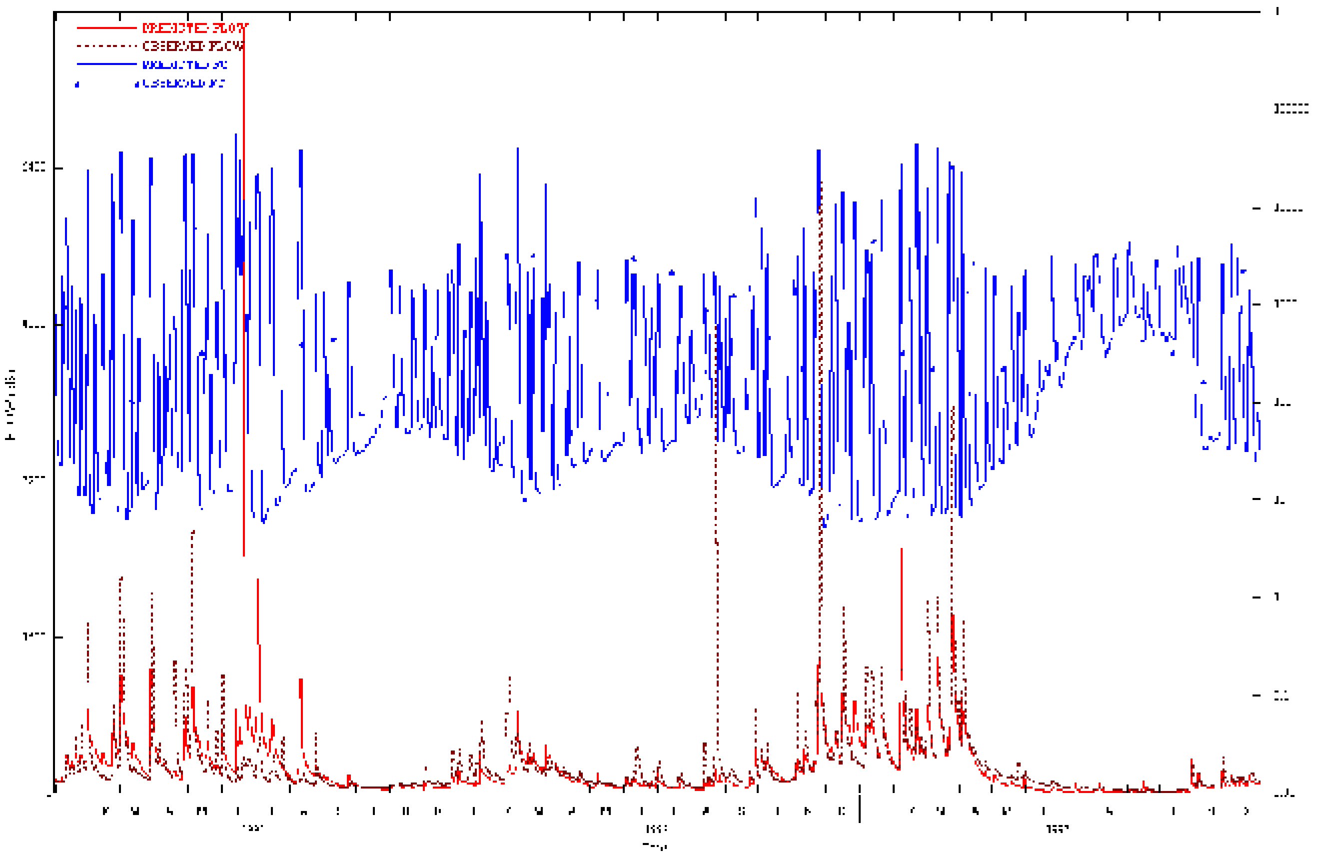

**Figure 1. Predicted and observed flow and FC for calibrated model.**

**Table 3. HSPF sensitivity to doubling of bacteria parameter values**

| Parameter | Effect of Doubling Value | RMSC[1] (%) |
|---|---|---|
| Beef cattle number | Higher FC concentrations | 43.4 |
| Dairy cattle number | Higher FC concentrations | 39.2 |
| Time beef cattle are in stream | Higher FC concentrations | 31.9 |
| First order in-stream decay rate | Lower FC concentrations during low flow | 28.3 |
| Poultry number | Slight increase | 5.4 |
| Septic system number or failure rate | Slight increase | 5.1 |
| Deer density | No discernable effect | 3.0 |

[1]Root mean squared change as a percentage in daily FC for the period 1/1/1992 to 12/31/1993.

Once we calibrated the model for stream flow and FC concentration, we tested the sensitivity of the model predictions of FC to bacteria parameters by doubling the values of the parameters, one by one. We compared the predicted daily FC concentrations before and after the change by calculating the root mean square change (RMSC) in predicted FC concentration during the period 1/1/1991 to 12/31/1993.

## RESULTS

Most HSPF parameters that affect water flow were calculated using known relationships with soils or landuse and using values from the HSPFParm database for HSPF simulations for the Piedmont region in Virginia (Donigian et al., 1999). Calibration was achieved primarily by adjusting the water flow parameters that affect the rate of recession during wet periods, the ground water recession rate, soil water storage, actual evapotranspiration, and the fraction of groundwater that is lost to deep flow. Predicted and observed daily stream flow are shown in Figure 1.

Uncalibrated predicted FC concentrations were three orders of magnitude higher than the observed values. In order to calibrate FC concentrations, we assumed that FC concentrations in beef cattle manure were three orders of magnitude less than the default values in the Bacteria Tool. For our calibration, we assumed that beef cattle were in streams five percent of the time based on the study by Matthews et al. (2003). Predicted and observed FC concentrations are also shown in Figure 1.

The most sensitive bacteria parameters were the number of beef cattle and dairy cattle in the watershed (Table 3). Doubling these value caused higher FC concentrations under all conditions. The effect of dairy cattle would have probably been less if we had reduced the assumed FC concentration in dairy as well as beef cattle during calibration. The third most sensitive parameter was the time that cattle spent in streams. The fourth most sensitive parameter was the first order in-stream decay rate.

The number of poultry, septic systems, and deer had little effect on the model predictions. The lack of effect of deer is probably due to the low density (5 animals per square mile) and the low runoff from forested lands. The lack of effect of chickens may be due to the assumption in the Bacterial Indicator Tool that chicken manure was applied to crop land, but not to pasture land (and most of the agricultural land was pasture in our watershed). Since it is a common practice to apply chicken manure to pastureland, the Bacterial Indicator Tool should be modified to allow this.

## CONCLUSIONS

Our study showed that HSPF predictions, used in conjunction with the Bacterial Indicator Tool, overestimated FC concentrations in the Little River watershed by three orders of magnitude. Once the model was calibrated, FC concentrations were most sensitive to beef and dairy cattle number, the time cattle spent in streams, and the in-stream decay rate. These results indicate that we need accurate information on the number of cattle within small watersheds (instead of county-wide statistics) and in-stream processes. Studies, such as that by Mathews et al. (2003), can help in quantifying the amount of time that cattle spend in streams. Our study also indicates the important effect that cattle in streams have on water quality.

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