APPLICATION OF SWAT HYDROLOGIC MODEL FOR TMDL DEVELOPMENT ON CHAPEL BRANCH CREEK WATERSHED, SC

D.M. Amatya[1], T.M. Williams[2], A.E. Edwards[3], N.S. Levine[4], D.R. Hitchcock[5]

AUTHORS: [1]Research Hydrologist, US Forest Service Center for Forested Wetlands Research, 3734 Highway 402, Cordesville, SC 29434; [2]Professor, Clemson's Baruch Research Institute of Coastal Ecology and Forest Science, Georgetown, SC; [3]Hydrotech, US Forest Service Center for Forested Wetlands Research, Cordesville, SC; [4]Assistant Professor, College of Charleston, Charleston, SC; [5]Assistant Professor, Baruch Institute, Agricultural and Biological Engineering Department, Clemson University, Georgetown, SC.

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Abstract. Watershed-scale hydrologic/water quality models are frequently used to characterize flow dynamics, pathways, and pollutant loading rates as a function of land use, soils, topography, management practices, and their interactions with variability in climate. SWAT (Soil and Water Assessment Tool) is a widely used GIS-based basin scale model to quantify the impact of land management practices on hydrology and water quality in large, complex watersheds including analysis for development of Total Maximum Daily Loads (TMDLs). In this project supported by SC DHEC's 319 Grant Program, SWAT has been used to evaluate nutrient loading and allocations based on source area identification and proposed best management practices (BMPs) for developing TMDLs for a 1,555 ha mixed land use watershed draining Chapel Branch Creek (CBC) to Lake Marion near Santee, SC. Lake Marion is an important recreational area for South Carolina, and the town of Santee, SC derives most of its economic activity from tourism. The creek is in SC DHEC's 2004 (303d) list of impaired water bodies for excessive N, P, chlorophyll-a, and pH.

In order to apply the SWAT model for scientifically valid determination of the nutrient loadings, it is first being calibrated for the hydrology component driving these loadings. Two years (2006-08) of rainfall data from three on-site gauges and weather data from a nearby station were used to simulate the stream flow rates across the watershed. The CBC watershed was delineated into smaller subwatersheds using the Arc-GIS SWAT2005 model with DEMs for topography, SSURGO data base for soils, NAIP2005 imagery for land use, and field observed drainage network. The model is being calibrated using flow rates measured at two stream locations draining major categories of land use. Once the model is calibrated for flow it will further be calibrated with the nutrients measured using auto-samplers at the same two locations. Event-based nutrient data collected at six other locations within the watershed will also be used for source area identification and validating the SWAT model that will be applied for load allocation analysis and TMDL development within the CBC stream. As the TMDL is developed, stakeholders will be included in order to earn their "buy-in" for the proposed BMPs for necessary load reductions. This project not only includes the TMDL development, but also the implementation of BMPs plus educational strategies for nonpoint pollution reduction.

INTRODUCTION

Chapel Branch Creek is a small tributary of the Santee River in central South Carolina. It has been listed by the South Carolina Department of Health and Environmental Control (SCDHEC) under EPA approved SC 2004 303(d) list of water bodies for impairment of aquatic life (AL) due to elevated chlorophyll-a, TN, TP, and pH. This conclusion was based on water quality data sampled by Santee-Cooper for the SC Department of Health and Environmental Control (DHEC) at Station (SC-014) about 1.5 km upstream from Lake Marion from 1996-2000. The watershed is small (1555 ha) by comparison to others but it has wide variety of potential nutrient sources.

The US Forest Service in conjunction with Clemson University and the College of Charleston are developing a Total Maximum Daily Load (TMDL) assessment and implementation project on Chapel Branch Creek using both a monitoring and modeling approach (Williams et al., 2007). Monitoring involves measuring stream flow in strategic locations on the watershed and water quality from potential source areas. The subsequent modeling approach includes calibration and validation procedures with site specific topographic, soil, land use, and vegetation spatial data along with measured climatic and stream flow data. Model outputs will be used to better understand the watershed hydrologic processes and thus to make decisions on alternative best management scenarios designed to reduce the negative impact of anthropogenic activities on water quantity and quality (Parajuli et al., 2008; Santhi et al., 2008; Moriasi et al, 2007). We have chosen SWAT as the primary hydrologic and water quality model for development of the TMDL. SWAT will be used to estimate flow and dissolved nitrogen and phosphorus loads on this diverse watershed. SWAT was chosen since much of the watershed is still agricultural. SWAT allows segregation of land use into hydrologic management units and spatial distribution into sub-catchments. SWAT has been integrated into the GIS program in ARC-GIS 9.1 with user interfaces to aide in watershed delineation and parameterization. In this paper we will discuss the procedures used with the Arc-SWAT model to develop sub-watersheds for its hydrologic calibration including difficulties in watershed delineation due to very flat terrain, and also hydrology and water quality monitoring approaches for its application for TMDL development.

METHODS

Site Description

Chapel Branch Creek watershed is located within the upper coastal plain region of Orangeburg County, South Carolina, adjacent to Lake Marion (Fig. 1). The CBC watershed drains a land area of 1560 ha at the edge of Lake Marion in the northeast quadrant (USDA, 2007). Topography of the watershed is characterized by flat lands at about 36.6 m a.m.s.l. in the upstream areas with somewhat steeper topography on the downstream section near Lake Marion. The watershed incorporates complex land use patterns with residential, commercial, and industrial areas interspersed among agricultural and forested lands. Agriculture has been the prime land use in the watershed with small grain and vegetables as the primary produce of the area. Most of the forested lands are located within Santee State Park on the left bank of the CBC. A major interstate highway (I-95) along with exit ramps, rest area access roads, highways through the Town of Santee, and a tourist destination are located within the watershed. Chapel Branch Creek watershed contains portions of three golf courses, a small urban center with fast food restaurants, motels, other tourist attractions, a fringe of suburban housing, and a sewage treatment plant for the town and I-95 rest stop (Fig. 2). Treated effluent from the plant is used to irrigate one of the golf courses. Soils reflect somewhat poorly and poorly drained paleudults with relatively heavy subsoil on the flat terrace surface. The lower watershed has excessively well drained soils with heavy subsoils as well as dune soils with sand throughout the profile.

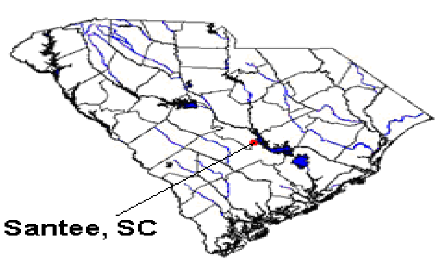

Figure 1. Location map of Chapel Branch Creek watershed (in red dot) at Lake Marion in Santee, SC.

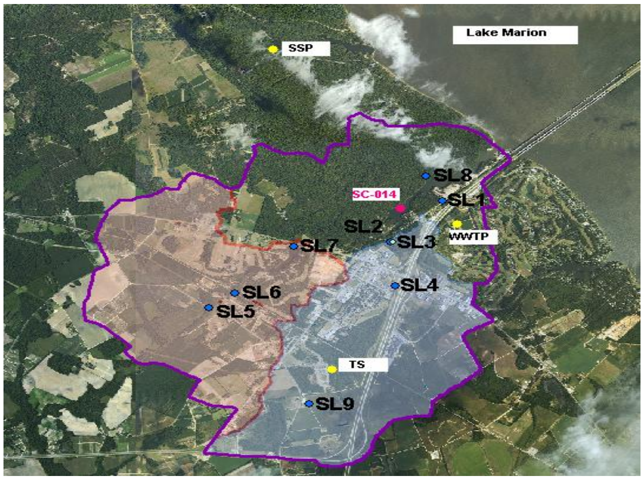

Figure 2. Delineation of Chapel Branch Creek watershed and the two smaller subwatersheds used for calibration, sampling locations (SLs), three rain gauges and SC-14.

Source Area Identification

Based on the analysis of GIS-based land use maps, aerial photography, and field visits all together nine locations (SL-1 to SL-9) (Fig. 2) in the whole watershed with the outlet at Lake Marion were identified to sample each of the various sources of potential contamination. SL-1 and SL-8 are located downstream of the SC-14 where TMDL is proposed to be developed.

Soil and Water Assessment Tool (SWAT model)

The SWAT model (Arnold et al., 1993) was chosen for this study because it is a public domain model with open code. Further, SWAT has been successfully applied to assess the hydrologic and water quality impact of land management practices on water, sediment, and agricultural chemicals in complex watersheds such as Chapel Branch with its varying soils, land uses and management conditions. The SWAT model has also been used extensively in TMDL development (Parajuli et al., 2008; Santhi et al., 2008; DiLuzio et al., 2002).

Elevation Data for SWAT model Watershed Delineation

Elevation data for the site are primarily from USGS quadrangle maps (South Carolina Department of Natural Resources, SCDNR 2005). The Chapel Branch Creek watershed is located on three Quadrangle sheets (Felderville, Saint Paul, and Vance), which were joined into a single file after converting different units of contour intervals into the same metric unit. The Quadrangle map contour lines were used to generate a best approximation of watershed and sub-watershed boundaries. A stream layer was developed by hand by digitizing stream, ditches and storm drainage structures using aerial photographic interpretation. This layer was further refined by ground truthing and three site visits. These user-defined, digitized stream networks and subwatershed layers are inputted with the DEM to create more accurate flow routing than using the DEM alone. Optional point sources such as the Wastewater Treatment Plant and reservoirs are added after SWAT calculates flow routing parameters. The final outlet (#1) (Fig. 2) for Chapel Branch Creek was chosen where the creek ends and Lake Marion begins, although the TMDL development ends upstream at SC-014.

Hydrologic Response Units (HRUs)

As a next step, Hydrologic Response Units (HRUs) were created by defining and overlaying the land use, soils, and slope in the entire watershed. A detailed shapefile of the land use was made using NAIP 2005, 1m resolution imagery (Mihalik, 2007). Small changes in the watershed boundary required additional digitization, as well as consolidation of detailed land use into fewer categories due to SWAT limitation of urban land use codes. SSURGO soil data was downloaded from the NRCS webpage which included a shapefile and database for SC-075 soil map for Orangeburg County. For the slope input, Multiple Slope was chosen with three slope classes of 0, >2, and, >5. Multiple HRUs were chosen with a percentage threshold of 10% for land use, soil class, and slope class.

Weather Input Tables

Next rainfall and other weather data were input into the model. Rainfall data from three installed automatic and manual gauges at the Town of Santee (TS), Wastewater Treatment Plant (WWTP), and Santee State Park (SSP) (Fig. 2) are being continuously measured since August 2006. All other data such as air temperature, relative humidity, solar radiation, and wind speed was obtained from the nearby US Fish and Wildlife Service weather station at Santee Wildlife Refuge across Lake Marion to the northeast. Hourly weather data were processed to obtain daily average values for calculating the daily potential evapotranspiration (PET) using Turc's method (Amatya et al., 1995). An option of US database was chosen to write the weather input files. The PET file name was input in the SWAT **.cio** file.

Editing of Input Tables

SWAT allows the user to edit the input tables after file creation. The watershed delineation also included a location for a small reservoir like pond at SL-7 and a similar large water body between the lake and SC-14. The reservoir data at SL-7 was entered using data obtained from an engineering report (ERC, 1999). Since the reservoir at SL7 is small, the **.rsvrng** file in the SWAT2005.mdb was edited to allow lower values for normal and emergency spillway volumes in the interface. Later during calibration, point source discharges, such as from the wastewater treatment plant (SL-1), will be added to further calibrate the model.

Stream Flows

Initially, only two of the nine locations (SL-2 and SL-7) draining two major tributaries of Chapel Branch Creek (Fig. 2) were instrumented with continuous ISCO flow meters and water quality samplers for calibrating the SWAT model. In this study data measured from March 2007 to July 2008 at SL-7 and from July 2007 to July 2008 at SL-2 are being used for analysis. Measured flow rates were further processed to obtain daily and monthly averages for SWAT model calibration.

Water Quality

All nine sites are being manually sampled for a single storm on a seasonal basis, while one storm per month will be sampled by the automated samplers. Water quality for nutrients (NO_3-N, NH_4-N, TKN, and TP) is being continuously measured since July 2007, mainly at sampling stations SL-2 and SL-7 (Fig. 2). Samples collected on a flow proportional basis using ISCO-3700 samplers are downloaded every week and taken to Santee Cooper Analytical and Biological Laboratory in Moncks Corner, SC for the analysis. Six discrete samples for a chosen event as well as a composite sample for each month are used for analysis as per the QAPP protocol.

SWAT Model Calibration

Figure 2 shows the two major sampling locations. SL-2 drains 555 ha area of Town of Santee, highways and roads, and some agricultural and forested lands and SL-7 drains 542 ha area of mostly agricultural and forested lands and a golf course, covering more than 2/3 the area of the watershed. Since there is no flow monitoring at the outlet of the entire watershed (Subwatershed 1) at Lake Marion, data from these two locations will be used to calibrate and validate the SWAT model. It is assumed that if validations and calibration work for these two sub-watersheds, then SWAT will be working for the entire watershed at the final outlet. After inserting all spatial and temporal input data, the SWAT model is being set up for a run with default parameters for remaining variables. In this study two years (2006-08) data are being used for the model calibration with 2006 just as a "warm-up" period not used for any analysis. Model predicted daily and monthly flow data at SL-2 and SL-7 will be used to compare with the measured data for needed calibration.

RESULTS

Monthly measured rainfall for 2007-08 at three gauges in the project area is shown in Figure 3.

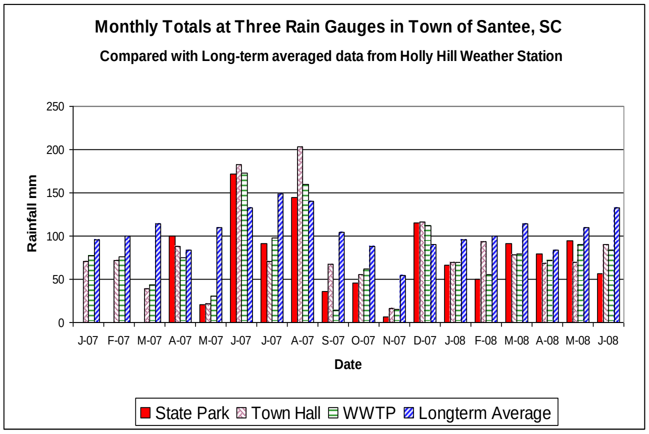

Figure 3. Measured monthly rainfall at three sites on Chapel Branch Creek watershed for 2007-08.

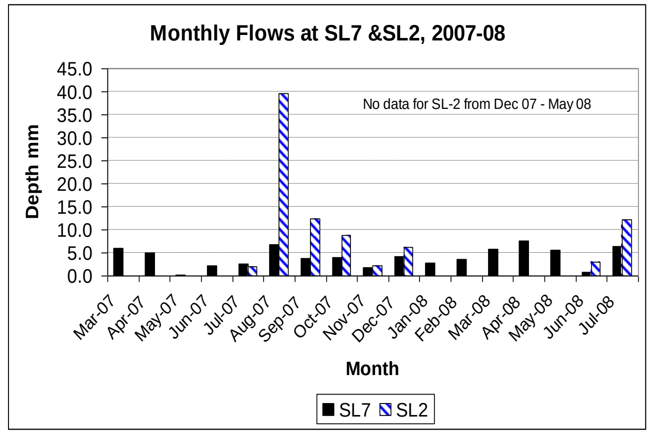

Figure 4. Measured monthly flow at three sites on Chapel Branch Creek watershed for 2007-08.

Both the year 2007 (970 mm rain) and half-year in 2008 (470 mm) were very dry years with lower amounts than the long-term average at the study site. Only the months of April, June and August in 2007 had rainfall in all three gauges higher than the long-term average for the nearby Holly Hill site. All gauges at the site have been recording consistently lower rain than the normal since September 2007 to date. The rain gauge at the Town Hall recorded 8-10% higher rainfall than the gauge at WWTP and SSP for the period of 2007-08, although no definitive monthly pattern was observed.

Monthly flow data measured at two major locations of SL-2 and SL-7 are shown in Figure 4. Although both watersheds were of similar sizes the total outflow from SL-2 (draining Town of Santee, Highways, Roads and some agricultural and forest areas) was consistently higher as much as six times than that from SL-7 (with agricultural/forest areas and a golf course) in August 2007. One reason for lower flows at SL-7 may be also due to a small reservoir that may allow for higher evaporation and deep seepage. No flow data was available for SL-2 from December 2007 to May 2008 due to instrument malfunction. The outflow measured for July-December 2007 at SL-2 was 71 mm compared to only 19 mm period for SL-7 with a reservoir. The calculated average runoff for July-December 2007 and June-July 2008 were 3.1% and 9.6%, respectively of the respective average rainfall. These runoff values are much lower than those for similar watersheds due to lower than normal rainfall and high spring-summer PET. The estimated annual PET for 2007 was 1217 mm and for the half-year of 2008 was 690 mm with values as high as 180 mm in May-June of both years.

Altogether 73 subwatersheds were obtained by using ArcGIS-SWAT interface tools for watershed delineation. The HRU definition process in SWAT created over 2000 HRUs for the entire watershed. Subwatersheds #23 and #30 represented the outlets at SL-2 and SL-7 with a small reservoir like pond, respectively, while the calibration is being performed. SWAT modeling results are not yet available due to issues with reservoir input in SWAT.

CONCLUSIONS AND NEXT STEPS

Hydrologic analysis of measured rainfall, runoff, and PET results showed that the study period 2007-08 was a much drier year compared to the long-term average. SWAT model setup including watershed boundary delineation with a regular procedure was proved to be a challenging task for this watershed with flat slope and complex drainage systems. Furthermore, the current Arc-SWAT in ArcGIS 9.1 was found to have some problems with SSURGO soils data and reservoir input setup and could be solved either by going back to ArcView 3.3 GIS or ArcGIS 9.2. Model setup and hydrologic calibration works using ArcView 3.3 and analysis of water quality (nutrients primarily) are already in progress as a second step for TMDL development.

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