USING THE HYDROLOGIC MODEL MIKE SHE TO ASSESS DISTURBANCE IMPACTS ON WATERSHED PROCESSES AND RESPONSES ACROSS THE SOUTHEASTERN U.S.

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Abstract-- A clear understanding of the basic hydrologic processes is needed to restore and manage watersheds across the diverse physiologic gradients in the Southeastern U.S. We evaluated a physically based, spatially distributed watershed hydrologic model called MIKE SHE/MIKE 11 to evaluate disturbance impacts on water use and yield across the region. Long-term forest hydrologic data from a southern Appalachian Mountain and a lower coastal plain watershed in South Carolina were used as model inputs. The model captured the temporal and spatial dynamics of shallow groundwater table movement and streamflow. Results suggest climate change and tree removal would have pronounced hydrologic effects; especially during dry periods. We also found that the data parameterization for even small scale distributed watershed-scale modeling remains challenging where spatial subsurface characteristics are often not known. The global change implications on hydrologic processes and response to in the two landscapes are discussed.

INTRODUCTION

Over half the land mass of the Southeastern U.S. is forested. The region has high biodiversity, and favorable climate for plant and animal growth, and human habitation. However, forest ecosystem services are threatened by global changes that include population growth, urban sprawl, climate change, and other natural and human stressors (Wear and Greis, 2004). These current and future biotic and abiotic changes will have long-term impacts on watershed ecosystems through their direct effects on the water cycle within the region (McNulty and others 1998). Although forested watersheds provide the best water, potential water quantity and water quality degradation from intensive forest management practices, landuse changes, wildfires and other disturbances is of regional concern (Swank and others 2001). Watershed management and restoration practices, such as Best Management Practices (BMPs) require an accurate understanding of the basic controlling factors of hydrologic processes at a watershed-scale across the diverse physiologic gradients in the Southeastern U.S. (Sun and others 2004)

The southeastern U.S. has a long history of forest hydrologic research (Jackson and others 2004; Amayta and others 2005). Over the past 50 years, numerous watershed manipulation experiments were conducted in strategic locations representing the three major physiographic regions across the southeast (i.e., coastal plain, piedmont, and mountain). The paired watershed experiments developed by those studies provided much of our current knowledge about the hydrologic processes and how watershed responds to disturbances and alternative land management practices. Past studies suggest that forest harvesting an increase in water yield and elevates groundwater tables due to the reduction of total ecosystem evapotranspiration. The increase in stream run-off has also been associated with elevated nutrient and sediment loading to streams (Swank and others 2001; Sun and others, 2001). Water quality effects diminish with vegetation regrowth and forest canopy cover restoration. The time required for canopy restoration to pre-disturbance levels is relative short compared to other part of the nation, and varies from a few years to several decades (Sun and others 2004). Synthesis studies in the southeast region (Sun and others 2002; Sun and others 2005) and worldwide literature (Andreassian 2004; Sun and others 2006) suggest that climate, soil, and topographic class (e.g., wetlands vs. uplands) control the hydrologic processes and responses to disturbance or land management. For example, shallow groundwater tables dictate the slow moving streamflow processes in forested watersheds on the flat coastal plains (Riekerk, 1989; Amayta and Skaggs, 2001) while hillslope processes and gravity (both saturated and unsaturated subsurface flows) control the water flow in steep mountain watersheds (Hewlett and Hibbert, 1967). Over 70% of precipitation returns to the atmosphere as evapotranspiration in the coastal watersheds due to high temperature, but upland watersheds in the piedmont and Mountains have a lower proportion of the total precipitation returned to the atmosphere as ET (i.e., 30-70% of precipitation) due to lower temperature and higher

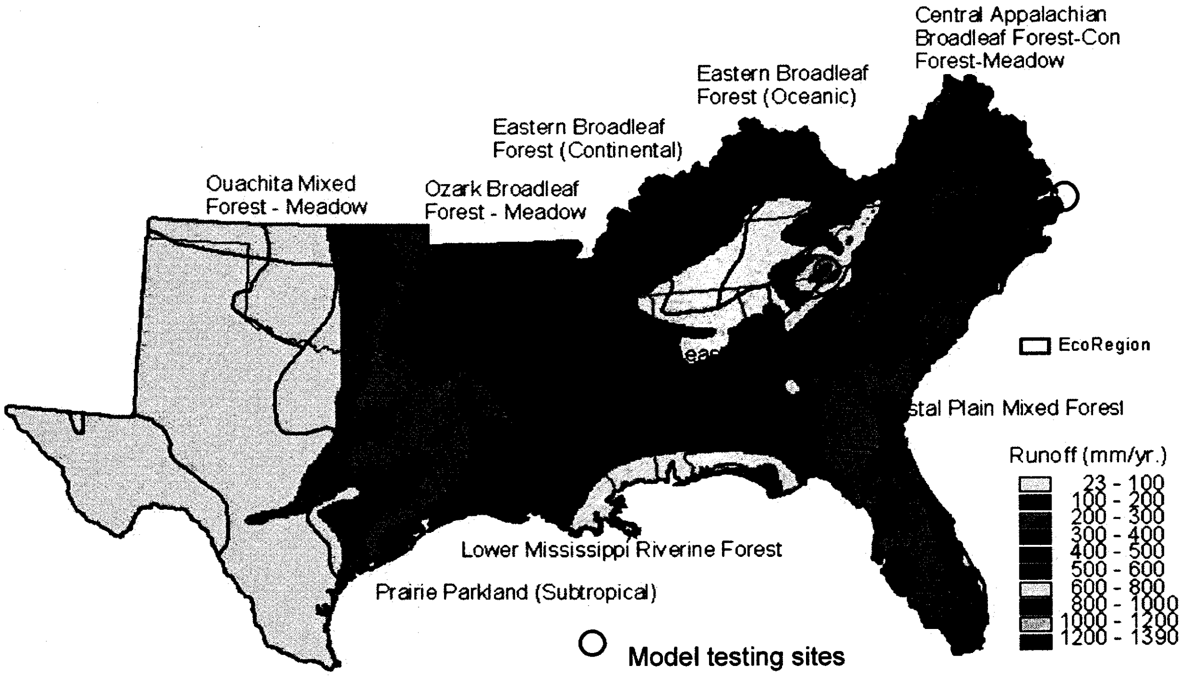


Figure 1 - Provinces of the Bailey ecoregion, annual runoff, and locations of model testing sites in the southeastern U.S.

The Santee Watershed 80 is located in the Santee Experimental Forest, part of the Francis Marion National Forest, on the lower Atlantic Coastal Plain, eastern South Carolina (33.15°N, 79.80°W) (Figure 2). As the control watershed for a paired watershed study, it was installed in the mid-1960s by the USDA Forest Service for studying forest management on water quality and quantity in the coastal plain geographic region (Amatya and others 2005; Harder, 2004). The watershed has a low topographic relief (< 4%) with surface elevation ranging from 3 - 10 m above mean sea level and consists of an ephemeral stream as the main drainage pathway.

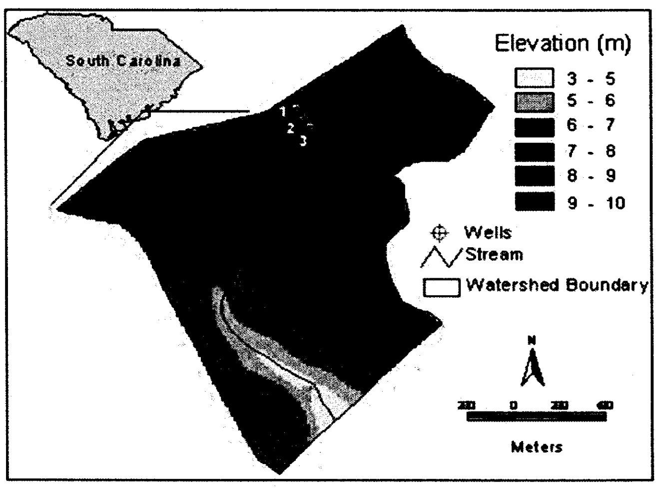


Figure 2 - Santee Watershed 80 topography and instrumentation.

The climate of the study site is classified as humid subtropical with long hot summers and short mild winters. Mean annual precipitation is about 1370 mm. July and August are the wettest months (receiving 28% of total annual precipitation) and April and November are the driest months (receiving 10% of total annual precipitation). January is the coldest month with a maximum average low air temperature of 10 °C, and July is the hottest month with a maximum average high air temperature of 28 °C. The mean annual air temperature is 19.1 °C. Approximately 23% of the watershed is classified as wetlands (Sun and others 2000). The forest coverage is mainly composed of pine-hardwood (39%), hardwood pine (28%) and mixed hardwoods (33%). Dominated tree species include loblolly pine (*Pinus taeda L.*), sweetgum (*Liquidambar styraciflua*), and a variety of oak species typical of the Atlantic Coastal Plain. Most of the trees are 17 years unsaturated soil water infiltration and redistribution processes are modeled using Richard's equation or a simple wetland soil water balance equation. Saturated water flow (groundwater) is simulated by a 3-D groundwater flow model similar to the MODFLOW model (McDonald and Harbaugh, 1988). Channel flows and channel surface water and upland groundwater interactions are handled by the MIKE 11 model and coupling of MIKE SHE and MIKE 11. MIKE 11 is a one-dimensional model that tracks channel water levels using a fully dynamic wave version of the Saint Venant equations. The coupling of MIKE SHE and MIKE 11 is especially important for simulating the dynamics of variable source areas in both wetland and upland watersheds. Detailed descriptions of the modeling procedures and mathematical formulation can be found in the MIKE SHE user's manual (DHI, 2004) and associated publications (Abbot and others 1986a, 1986b; Graham and Butts 2005).

Identical graphical and statistical methods were used to evaluate models performance for the two watersheds. The statistical measures included mean estimation error (ME), Correlation Coefficient (R) and the Nash-Sutcliffe (1970) coefficient of efficiency (E). The model was first calibrated with data from 2003 for the Santee and for data from for each site for 2003 with data from 1988 to 1989 for the Coweeta watershed. The models were validated with 2004 data from Santee and with from 1985-1987 and 1990 for Coweeta (Table 1).

Model Application Scenarios

After model calibration and validation were conducted, the MIKE SHE model was applied to four scenarios for both watersheds. These scenarios included: 1) Base line (BL); 2) Clear Cutting (CC); 3) a average annual temperature increase of 2 °C (TI); and 4) a average annual precipitation decrease (PD) of 10%. The purpose of the scenarios were to examine watershed hydrologic response land management and climate change.

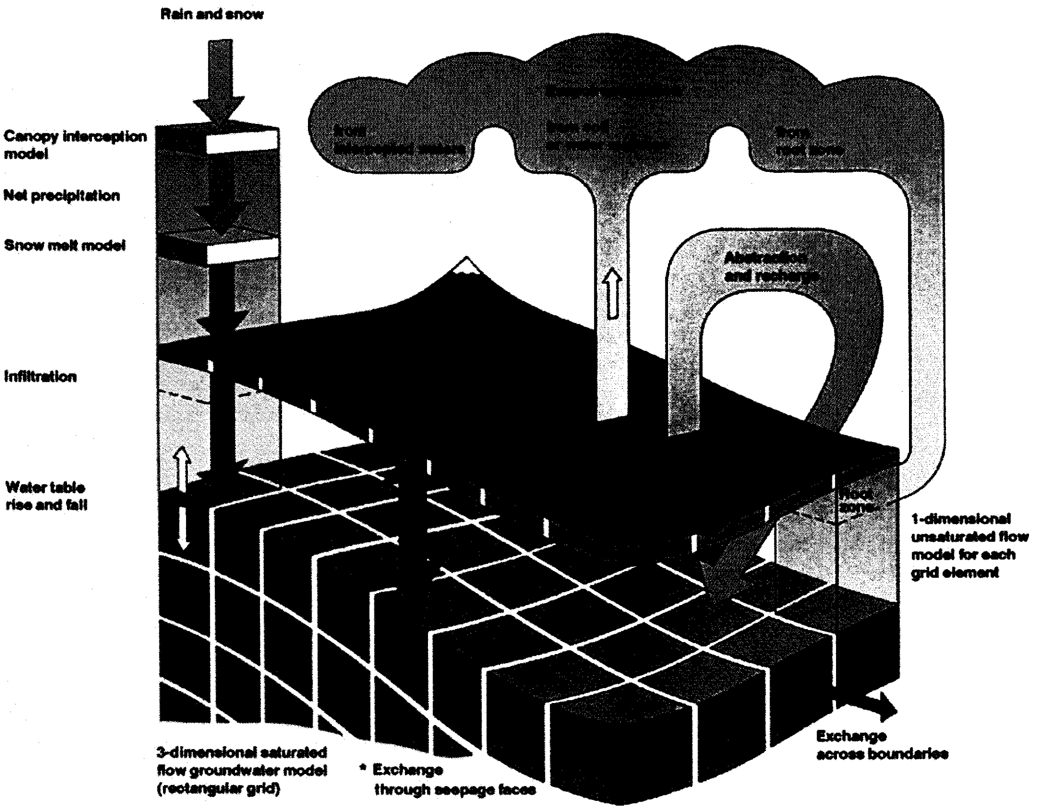


Figure 4 – MIKE SHE Model structure and hydrologic components(DHI, 2004)

At the daily basis, the biggest differences in streamflow were found in January of 1988 and during the summer of 1989. The approximately 7 mm day^{-1} over estimate of streamflow in the early 1988 may have been partially caused by poor estimates of initial conditions. The base line simulation run from 1985 to 1990 showed that the difference in predicted and measured streamflow was reduced to 5 mm day^{-1} for that particular date. The largest discrepancy in the summer of 1989 may have been due to the relatively shallow soil depth used in this modeling study. We used the same soil parameters to a depth of 3 m since there was no data available for soil properties below the 1.8 m depth. The soil properties were distributed uniformly across the entire watershed. In reality, the soil depth is likely to be highly variable across the watershed (Yeakley 1993; Miner 1968).

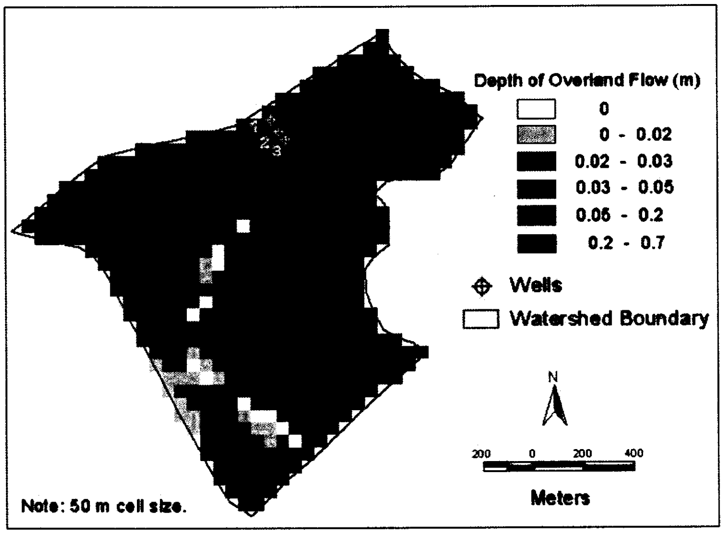


Figure 6 – Simulated spatial distribution of overland flow depth on 06-20-2003 at Santee watershed. Spatial rsoulution is 50 m.

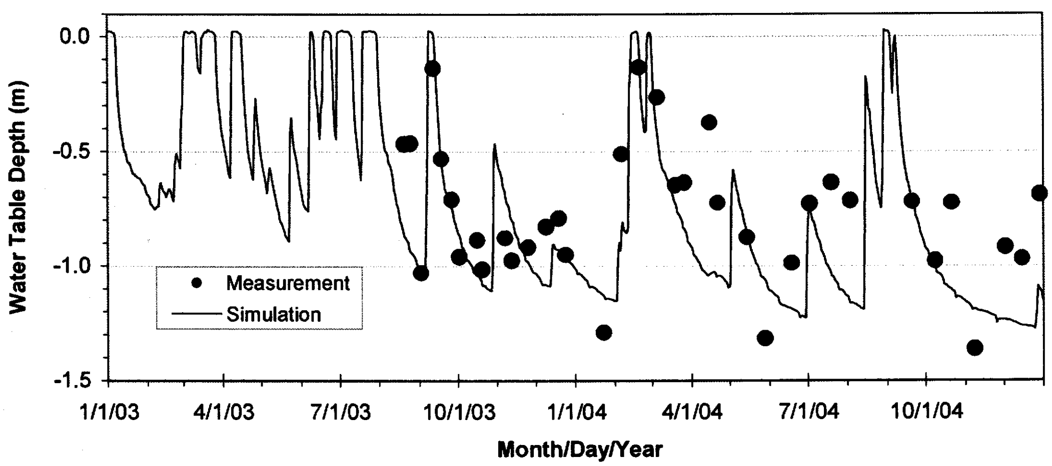
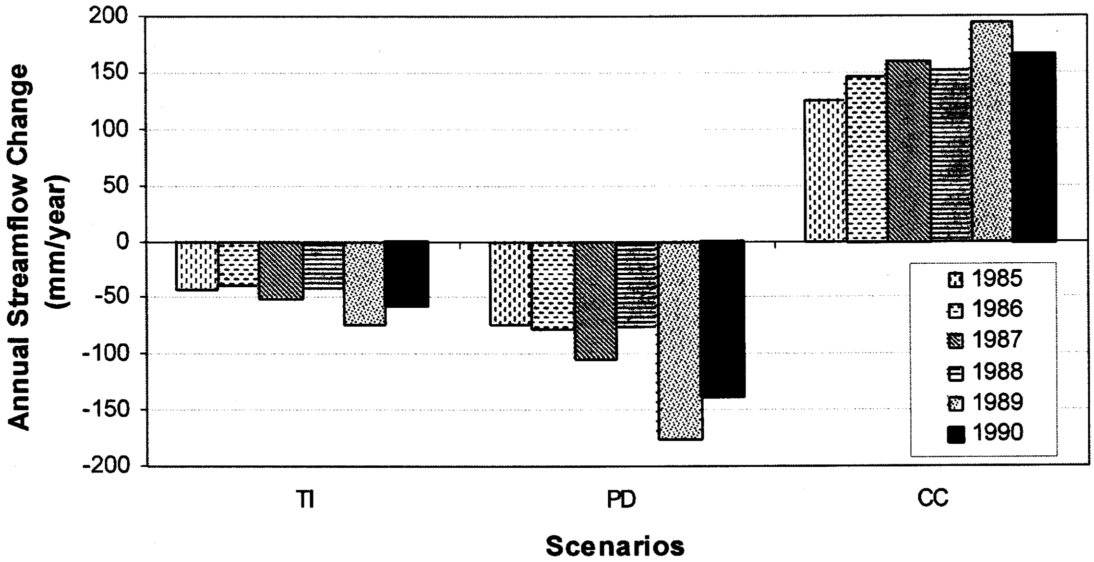


Figure 7 - Validation of MIKE SHE model with water table depth at Well 1 during October 2003 - December 2004 at Santee Watershed 80.

The MIKE SHE model was validated with the daily streamflow data recorded in 1985-1987 and 1990 (Figure 9). Compared to the long-term average precipitation at the watershed, 1985-1987 were extreme dry years and 1990 was a wet year. The model generally could match the streamflow dynamics with R = 0.85, ME = 0.04 mm day^{-1} and E = 0.72. Simulated streamflow values were close to measured except for the big storms in February and March of 1990 when the model overestimated daily daily streamflow values up to 10 mm day^{-1}. On an annual basis, the model had a tendency to over-predict streamflow in a dry year and under-predict streamflow it in a wet year.

periods when the ET differences between the baseline (BL) and disturbed scenarios were largest. Harvesting reduces leaf area and will result in a decrease in potential ET. Plant transpiration capacity and total ecosystem ET will decrease, and therefore soil water recharge for streamflow generation will increase. Increase in temperature by 2°C caused increase in PET, while decrease 10% precipitation caused direct soil water recharge. Both climate change scenarios will result in lower water table level.



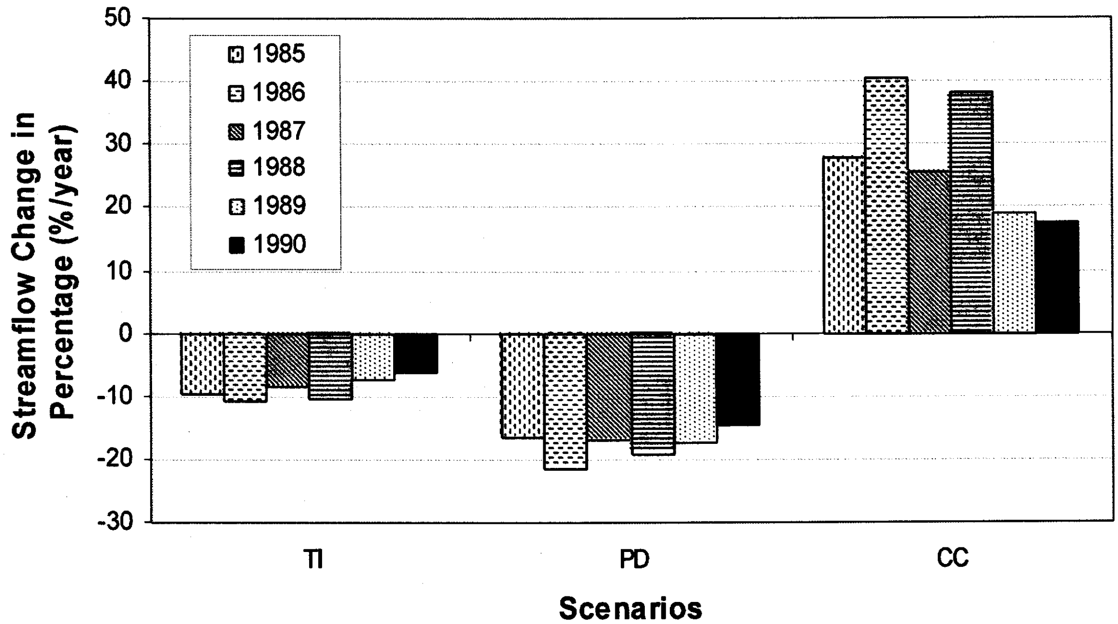


Figure 10. Simulated effects of clearcutting (CC), increase of air temperature by 2°C (TI), decrease of precipitation by 10% on streamflow as expressed by: a) change in absolute annual streamflow amount, b) change in percentage of annual streamflow at the Coweeta Watershed 2. For the CC case, a 30% reduction of potential ET was assumed (Grace and Skaggs, 2006; Sun, G. Unpublished data).

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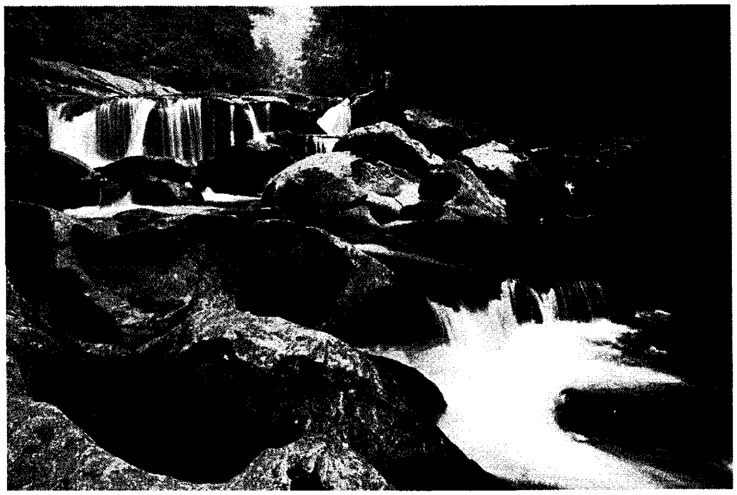

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