Estimating Impacts of Future Rainfall Change on Stream Flow and Sediment Load in Lower Yazoo River Watershed Using BASINS-HSPF-CAT Modeling System

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Climate change over the past several decades has resulted in shifting rainfall pattern and modifying rainfall intensity, which has, in turn, exacerbated stream flow and sediment load and imposed uncertainties to these processes. This study projected impacts of potential future rainfall variations on stream flow and sediment load from the Lower Yazoo River Watershed (LYRW) in Mississippi using the BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)-HSPF (Hydrological Simulation Program-FORTRAN)-CAT (Climate Assessment Tool) modeling system. Several simulation scenarios were performed to investigate impacts of different future rainfall rates on stream discharge and sediment load in the LYRW. Results showed that over a ten-year simulation period, an increase in the rainfall rate by 10% and 20%, respectively, resulted in increasing discharge by 8.1% and 7.4% as well as in increasing sediment load by 1.1 and 1.2 times. A potential future wet climate had discernable impacts on stream flow and sediment load in the LYRW. The BASINS-HSPF-CAT modeling system is a useful tool to modify historical rainfall data to project future rainfall impacts on watershed hydrological processes and sediment load due to climate change.

Introduction

Climate change over the last several decades has resulted in modifying precipitation pattern and intensity (Bates et al., 2008). Precipitation change has resulted wetting in the Northern Hemisphere mid-latitudes, drying in the Northern Hemisphere subtropics and tropics, and moistening in the Southern Hemisphere subtropics and deep tropics in recent decades as detailed by Zhang et al. (2007) and Bates, et al. (2008). Bates et al. (2008) reported that heavy rainfall has increased over most areas, whereas the very dry land area has increased more than double globally since 1970s. Tank et al. (2009) stated that air temperature in 2100 is expected to be 1.1- 6.4°C higher than that in 1900, accompanied by changes in rainfall intensity and amount. Each of the past three decades has been successively warmer than any previous decades based on instrumental records and the decade of the 2000s has been the warmest (Tank, et al., 2009).

Estimate of stream flow is central to water resource management, water supply engineering, environmental protection, and ecological restoration (Ouyang et al., 2015). In climate vulnerability assessment, stream flow is an important indicator of water response to the climate change. To mitigate the likelihood of future climate impact on stream flow, water resource managers must be able to assess potential risks and opportunities, and where appropriate, implement practices for adapting to future climatic conditions (Pielke & de Guenni 2004). Sediments in rivers are increasingly recognized as both a carrier and potential source of contaminants in aquatic environments due to their adsorption of toxic chemicals (Ouyang et al., 2002). Significant changes in river discharge, stage, and morphology as a result of sediment deposition have become an issue of concern due to the broad impacts upon terrestrial and aquatic life as well as river hydrology (Simon et al., 2002).

Changes in agricultural and forest practices, clearcutting in bottomland hardwood forests, and conversions from forests to agricultural lands are largely responsible for the increases in flooding, low stream flow, and sediment load in the Lower Mississippi River Alluvial Valley (LMRAV) (Zhang and Schilling 2006). Despite great efforts have devoted to investigating the impacts of agricultural, forestry, industrial, and urban activities on stream flow and sediment load in the LMRAV (Simon et al., 2002; Zhang and Schilling 2006; Shields et al., 2009; Ouyang et al., 2013), our literature search revealed that studies on the impacts of future climate change upon these issues in this region are fragmented and poorly documented.

The goal of this study was to assess the impacts of future rainfall variations due to climate change upon stream flow and sediment load from the LYRW in the LMRAV, using the US-EPA (Environmental Protection Agency)'s BASINS-HSPF-CAT modeling system. Our specific objectives were to: (1) develop a BASINS-HSPF-CAT model for the LYRW; and (2) apply the resulted model to investigate daily and annual stream flow and sediment load in the LYRW as affected by potential rainfall variations due to climate change.

Materials and Methods

Study sites

The LYRW is located in south Yazoo River Basin (YRB), Mississippi (Fig. 1). This watershed consists of 61 % forest land and 31% agriculture land with soil types of sand, loam, and clay. Surface water pollution within the YRB includes excess nutrients, sediments, heavy metals, and herbicides, which are the results of storm water runoff, discharge from ditches and creeks, groundwater seepage, aquatic weed control, naturally-occurring organic inputs, and atmospheric deposition (Nett et al., 2004; Pennington, 2004). An elaborate description of the study site can be found in Ouyang et al. (2013).

Model description

The US-EPA watershed modeling system, BASINS-HSPF-CAT, was selected for this study. BASINS is a multipurpose environmental analysis system for use by regional, state, and local agencies, research institutes and universities to perform watershed hydrology and water quality studies. HSPF is a comprehensive model developed by Aqua Terra Inc. through US-EPA for simulating water quantity and quality in watersheds of almost any size and complexity (Bicknell et al. 2001). The CAT model was first incorporated into US-EPA's BASINS modeling system in 2007 with the goal of increasing the capacity of BASINS users to conduct watershed based studies due to potential climate variability and change on water resources (US-EPA, 2009). CAT provides flexible capabilities for creating climate change scenarios, allowing users to quickly assess a wide range of "what if" questions about how weather and climate could affect watershed systems using the HSPF, SWAT, and SWMM models. A post-processing capability is also provided for calculating management targets to water resource managers. Climate change scenarios can be created with CAT by selecting and modifying an arbitrary base period of historical temperature and precipitation data to reflect any desired future changes.

Model development

Development of a HSPF model in the BASINS starts with watershed delineation. The processes include to setup a digital elevation model, create the stream networks, and select watershed inlets or outlets. The HSPF model also requires land use and soil data to determine the area and the hydrologic parameters of each land use pattern. This was accomplished by using the land use and soil classification tool in BASINS (version 4.2). The major steps in watershed modeling with HSPF are the mathematical description of the watershed, the preparation of input meteorological and hydrological time series, and the estimation of input parameter values through model calibration and validation. The time series are fed to the model by utilizing a standalone program called the Watershed Data Management program (WDM) provided in BASINS. The hydrologic and sediment components of the HSPF model have been calibrated and validated previously (Ouyang et al., 2013 and 2015).

Simulation scenarios

To gain a better understanding of potential future rainfall impacts on stream flow and sediment load in the LYRW, three simulation scenarios were performed in this study. The first scenario (base scenario) was chosen to predict daily and annual stream flow and sediment load with historical rainfalls. The second and third scenarios were the same as the first scenario except that the rainfall rate was increased by 10% for the second scenario and by 20% for the third scenario. Comparison of simulation results from the three scenarios allowed us to evaluate the potential impacts of future rainfall variations due to climate change upon the daily and annual stream flow and sediment load. The reason for selecting the wet climate with an increasing rainfall rate in this study was that the historical data have shown an increasing trend of rainfall through the years in this region.

Results and Discussion

Daily variations of stream discharge for the three rainfall settings (i.e., base rainfall, increased by 10%, and increased by 20%) in the LYRW are shown in Fig. 2. The base rainfall data were obtained from the local weather station and further computed to fill the gaps for representing the average rainfall condition at the LYRW, whereas the other two sets of rainfall data were attained by increasing 10 and 20% of base rainfall data to account for wet climate through the CAT model. Simulation results showed that an increase in rainfall rate boosted stream discharge although the percent increase in rainfall rate was not necessary proportional to the percent increase in stream discharge (Fig. 2). Analogous to the case of stream discharge, the daily stream sediment concentration in the LYRW increased with the rainfall rate (Fig. 3). Therefore, a potential future wet climate had great impacts on daily stream flow and sediment concentration in the LYRW.

Annual stream discharge and sediment load through the LYRW for the three rainfall settings are shown in Figs. 4 and 5. Over a 10-year simulation period, an increase in rainfall rates of 10% and 20%, respectively, resulted in increasing stream discharge by 8.1% and 7.4%. Similarly, over a 10-year simulation period, an increase in rainfall rates of 10% and 20%, respectively, resulted in increasing sediment load by 1.1 and 1.2 times. Therefore, a potential future wet climate could have discernable impacts on stream flow and sediment load at the LYRW watershed. The BASINS-HSPF-CAT modeling system is a useful tool to modify historical rainfall data to project future rainfall impacts on watershed hydrological processes and sediment load due to climate change.

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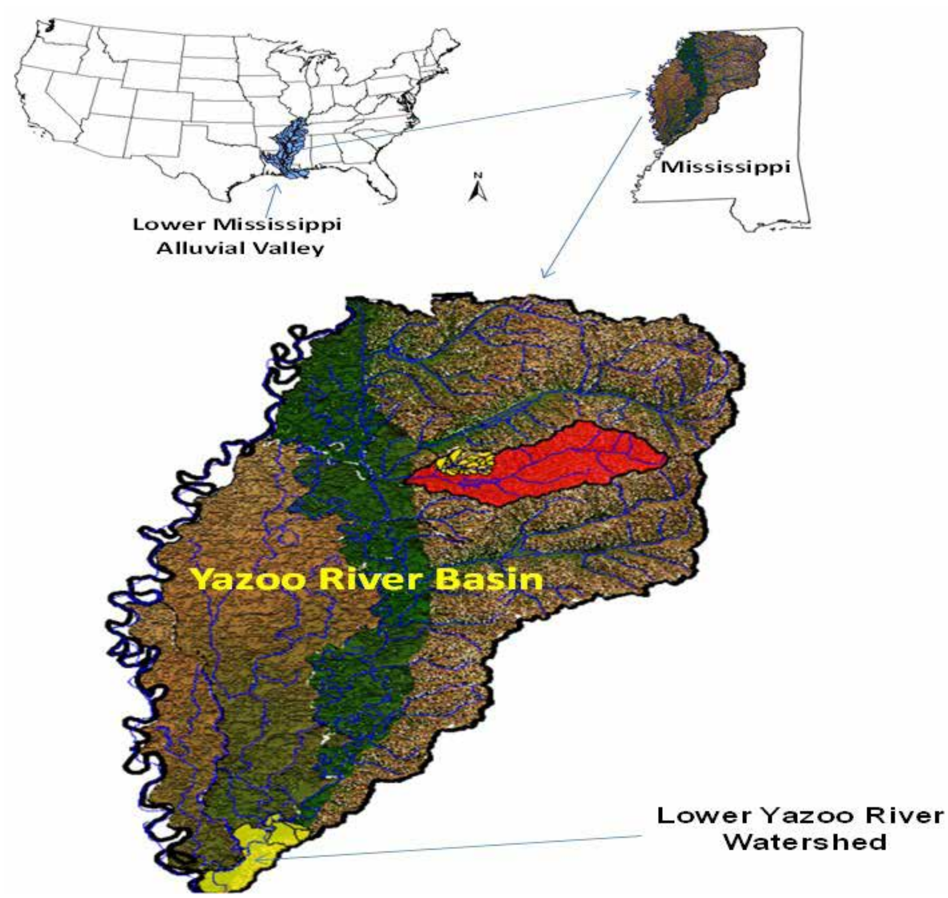

Figure 1. Location of the Lower Yazoo River Watershed.

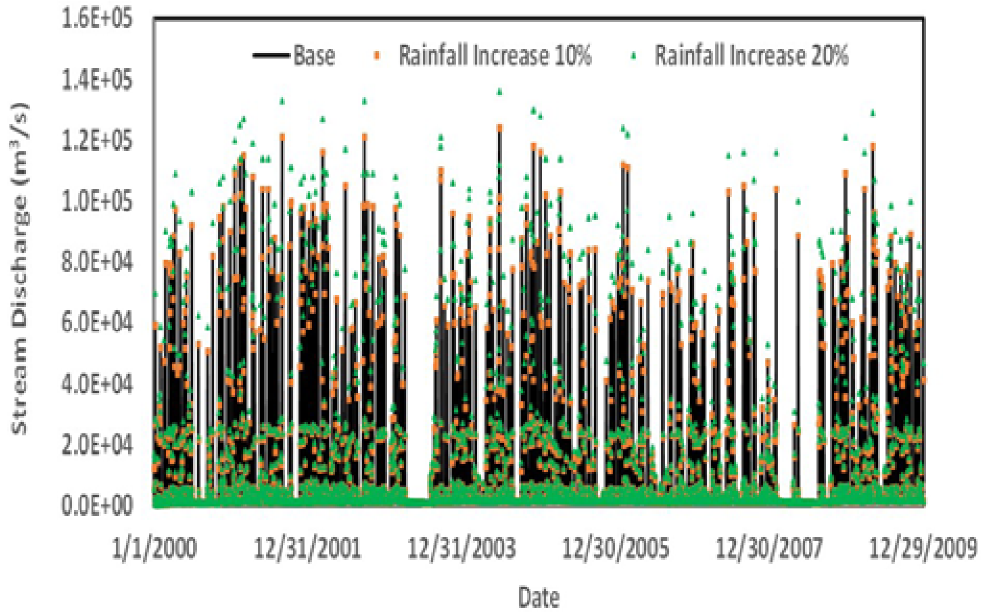

Figure 2. Daily stream discharge as rainfall rate increased.

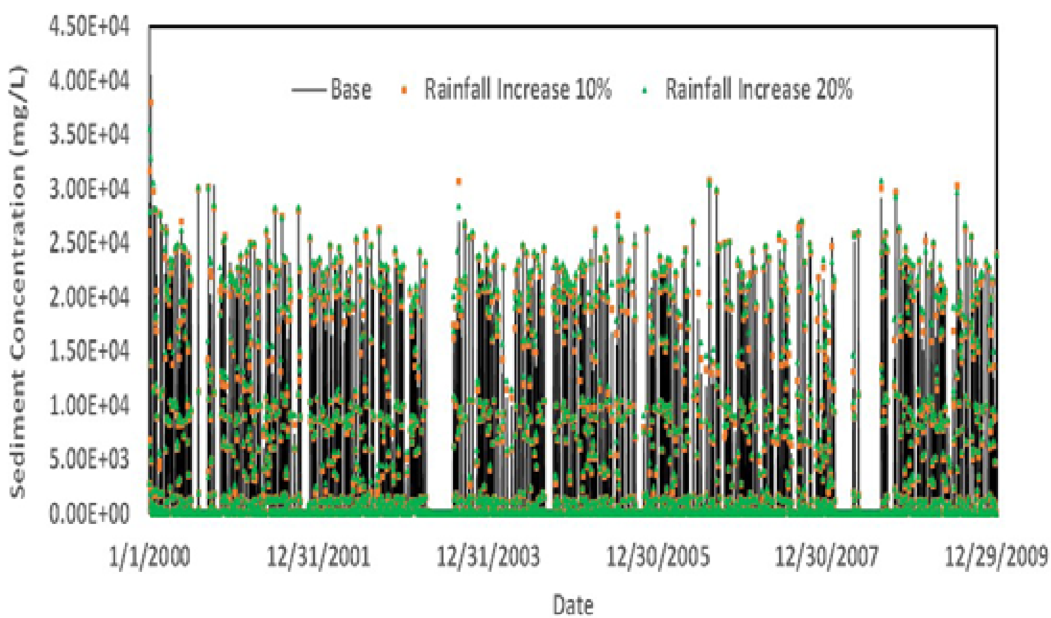

Figure 3. Daily sediment concentration as rainfall rate increased.

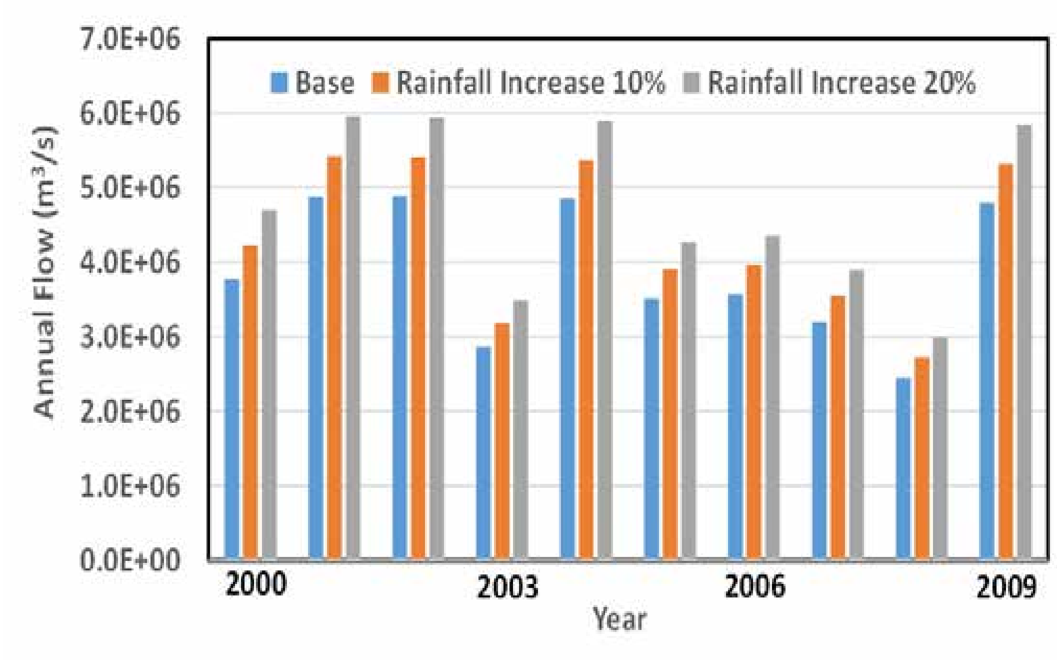

Figure 4. Annual stream discharge as rainfall rate increased.

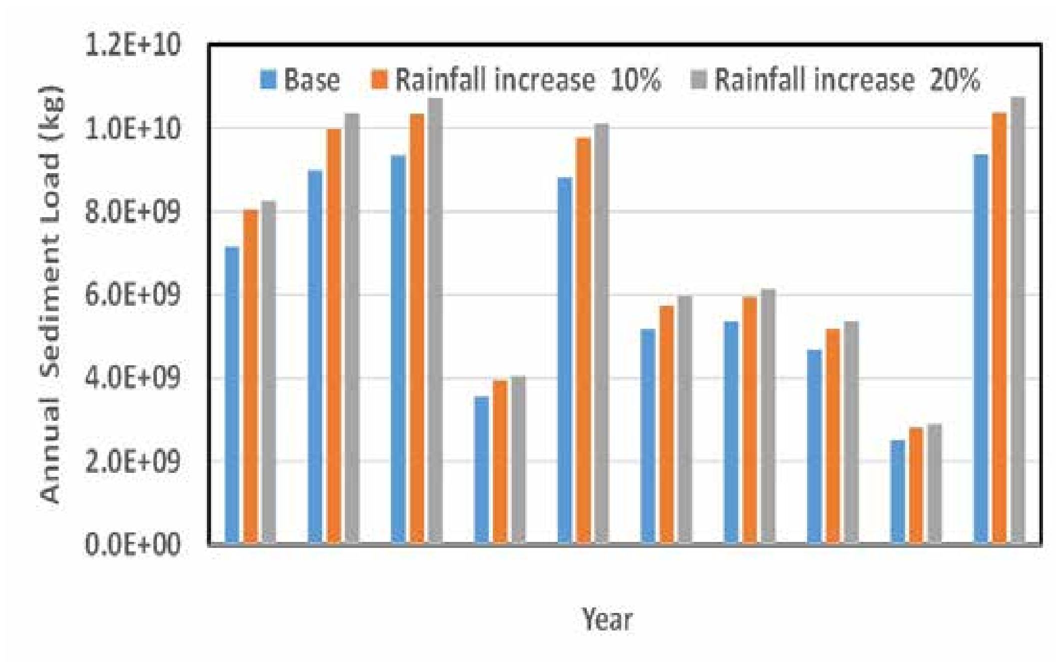

Figure 5. Annual sediment load as rainfall rate increased.