Impacts of Best Management Practices on Sediment and Nutrient Yields Under Multiple Climate Change Scenarios for the Meramec River Watershed

CHIN-LUNG WU[1], Jason Knouft[1], and Maria Chu[2]

[1]Saint Louis University
[2]University of Illinois Urbana-Champaign

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Abstract

Climate change is a primary factor influencing alterations in watershed hydrology. Associated changes in temperature and precipitation can influence the fate and transport of non-point source pollution within a watershed, which complicates the application of best management practices (BMPs) for pollution mitigation. Understanding the sensitivity of BMP implementation as climate change is critical for proper management of water resources. The objective of this study is to understand the effects of BMPs on sediment and nutrient yields in the Meramec River watershed in eastern Missouri, U.S.A due to changes in climate. The Soil and Water Assessment Tool (SWAT) was used to model the flow, sediment and nutrient yields across the watershed. Multi-site calibration (1996-2012) and validation (1981-1995; 2012-2014) gave varied results, ranging from very good to acceptable, for the monthly flow, sediment load, total nitrogen (TN) and total phosphorus (TP). Various BMPs were implemented into the calibrated model in conjunction with climate data from four Coupled Model Intercomparison Project Phase 5(CMIP5) projections to estimate the effects of climate change on watershed yields. Implemented BMPs include riparian buffers, vegetated filter strips, terrace, grassed waterway, and tillage. BMPs were implemented in subwatersheds with high sediment and nutrient outputs as well as relatively high ecological value. Results indicate that BMPs could achieve reductions in a range from 2 to 76% for sediment loss, 1 to 64% for TN loss, and 5 to 54% for TP loss. Among the individual BMPs assessed, vegetated filter strips were most effective when considering the reduction in sediment and nutrient loads. This study highlights the effectiveness of a range of BMPs in reducing the sediment and nutrient loads and provides quantitative measures for determining the most effective individual BMP and the optimal combination of BMPs based on current and future climate scenarios.

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chinlung.wu@slu.edu

Chin-Lung Wu[1], Jason H. Knouft[1], Maria L. Chu[2]

[1] Department of Biology, Saint Louis University, Saint Louis, MO.

[2] Agricultural and Biological Engineering, University of Illinois Urbana-Champaign, Champaign, IL

Background

Climate change is a primary factor influencing alterations in watershed hydrology. Associated changes in precipitation and temperature can influence the fate and transport of non-point source pollution within a watershed, which complicates the application of best management practices (BMPs) for pollution mitigation. Understanding the sensitivity of BMP implementation as climate changes is critical for proper management of water resources.

Objectives

To understand the effects of various BMPs on sediment and nutrient yields in the Meramec River watershed in eastern Missouri, U.S.A due to changes in climate.

Materials and Methods

- **The Meramec River Basin, covering an area of 10,270 km², is located in east-central Missouri on the northeastern flank of the Salem Plateau (Fig. 1). Annual precipitation is approximately 1040 mm. The primary land uses are forest (68%), pasture (19%) and urban (8%).**
- **Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998)**
- **SWAT inputs:1) Daily precipitation (10 stations), and max and min air temperature (4 stations); 2) topographic data (30m×30m); 3) land use land cover 2011 and land cover without urbanization and agriculture, 4) soil data (SSURGO).**
- **Model calibration and validation - Calibration: 1996-2012; Validation: 1981-1995, 2013-2014.**
- **Calibrated variables: flow, sediment load, Nitrate (NO3), Total Phosphorus (TP)**
- **Model performance metrics: Coefficient of determination (R^2), Nash-Sutcliffe coefficient (NSE).**
- **Proposed Best Management Practices (BMPs): grassed waterway (all), filter strip (agricultural and pasture lands), terrace (agricultural land), riparian buffer (300ft; all).**
- **BMP site selection: high in biodiversity values (Conservation Action Area; Fig. 2), high in subbasin sediment and nutrient yields.**
- **Climate data: 67 projections generated by 20 GCMs from Coupled model inter-comparison project phase 5 (CMIP-5), and projections span four representative concentration pathways (RCPs) for greenhouse gas emissions (Reclamation, 2013).**
- **Baseline: 1981-2000; future climate change scenario: 2040-2069 (mid 21st century)**
- **GCMs selection: GCMs with the highest, median and lowest changes in precipitation and air temperature in the mid 21st century.**

Results

- **For the model calibration and validation, R^2 varies from 0.71 to 0.89 while NSE varies from 0.69 to 0.89 for streamflow. For sediment load, R^2 and NSE were 0.91 for the calibration. During the validation period, R^2 and NSE were 0.53 and 0.37, respectively. Given the limited sediment load measurements and the associated uncertainty, the model's performance in sediment simulation is acceptable.**
- **Model's performance simulating NO3 and TP were evaluated only by R^2, mainly due to the uncertainty on field measurements and lack of continuous monitoring data. For the Nitrate, R^2 ranges from 0.09-0.34 during the calibration and from 0.04-0.27 during the validation. Model's performance for TP simulation was slightly better with R^2 ranging from 0.37-0.65 and 0.15-0.22 for the calibration and validation periods, respectively.**

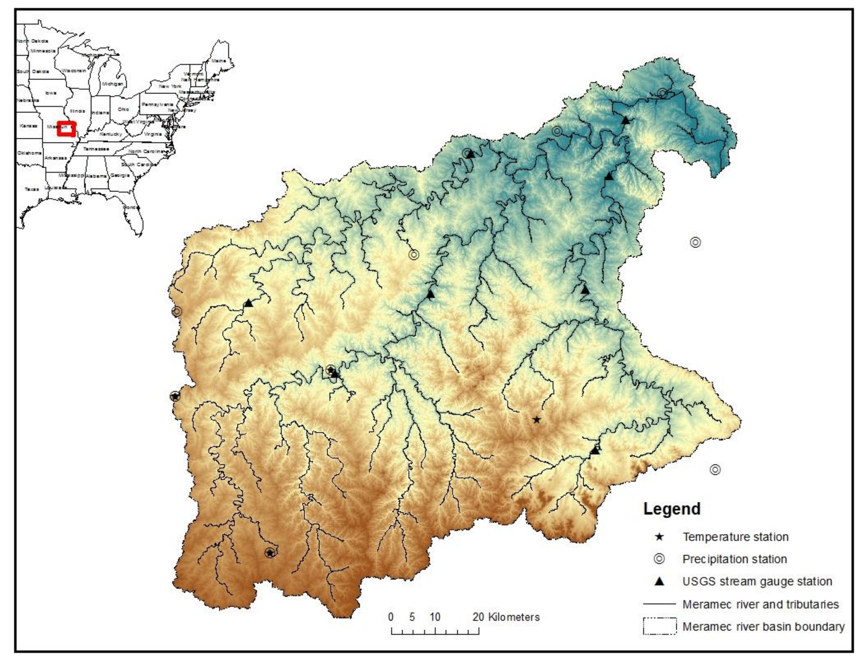

Figure 1. Locations of the Meramec River Basin, streamflow gauges, precipitation and temperature stations.

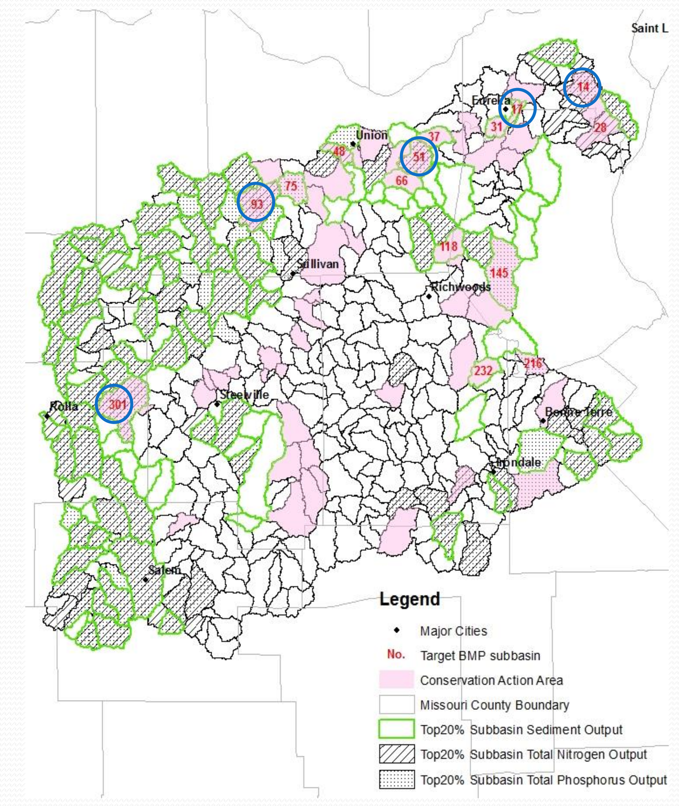

Figure 2. Locations of the conservation action area, the hotspots for sediment and nutrient, and the target subbasins for BMP implementation.

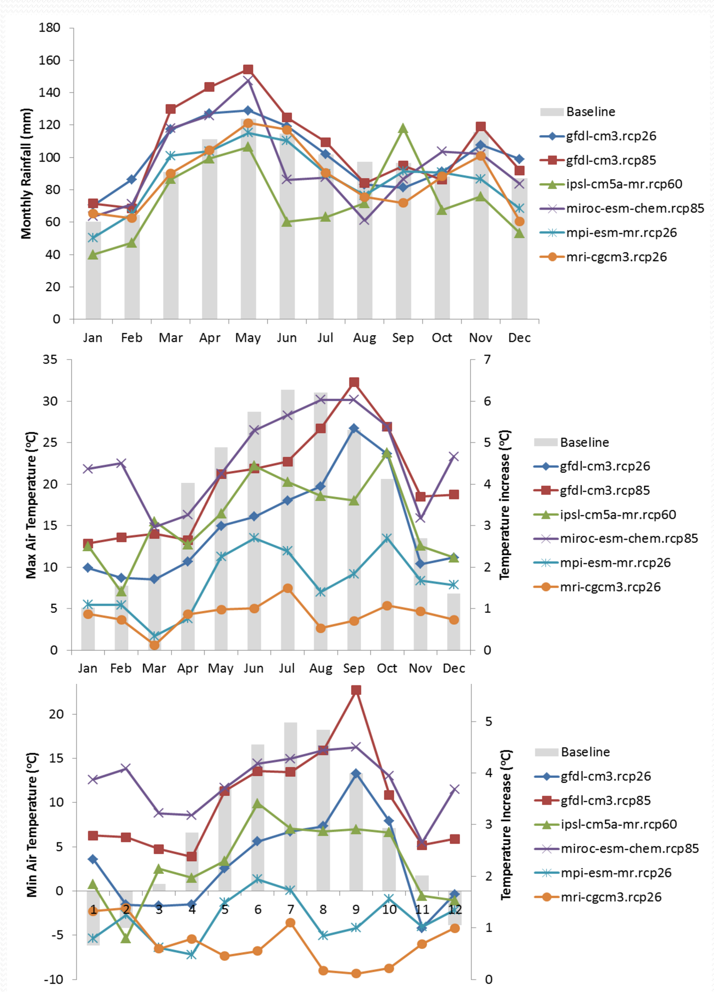

Figure 3. Average monthly rainfall distribution scenarios in 2040-2069 as compared to baseline (1981–2011). Maximum (a) and minimum (b) future temperature change °C reference to baseline period.

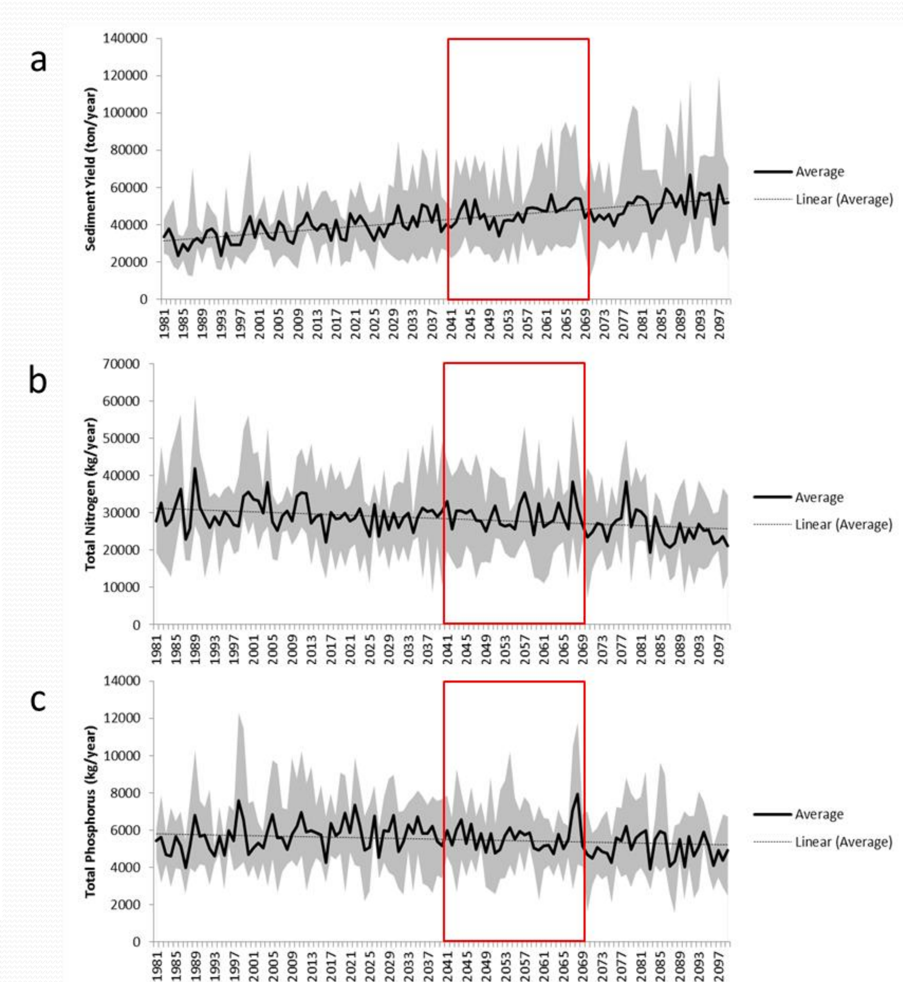

Figure 4. Maximum, minimum, and average of sediment (a), TN (b), and TP (c) yields and their trends under 6 projections. The 2040-2069 period is highlighted as the period within the red box.

Results (cont.)

- **By averaging all 67 projections, annual precipitation is projected to increase by 33.2mm (3.2%); while increases in maximum and minimum air temperature are 2.5 °C and 2.4 °C, respectively, in the mid 21st century compared with the baseline condition.**
- **Projected precipitation increases in the spring season and decreases in all other seasons during the mid 21st century (Fig. 3). All the selected projections have shown an increase in maximum and minimum temperature (Fig. 3), and this is likely to result in a decrease in flow as well as sediment and nutrient (Fig. 4).**
- **Results show that grassed waterway BMP can achieve reductions in a range from 58% to 80% for sediment loss, 15 to 43% for TP loss (Fig. 5).**
- **On average, implementing the filter strip BMP can reduce sediment, TN, and TP outputs by 28%, 64%, and 46%, respectively (Fig. 6).**
- **Percentage change in sediment, TN and TP yields displayed a wide range of variation from 1 to 85% under the riparian buffer BMP. Percentage change in reduction is positively correlated with the amount of areas in the buffer zone that are converted to forest land use (Fig. 8).**

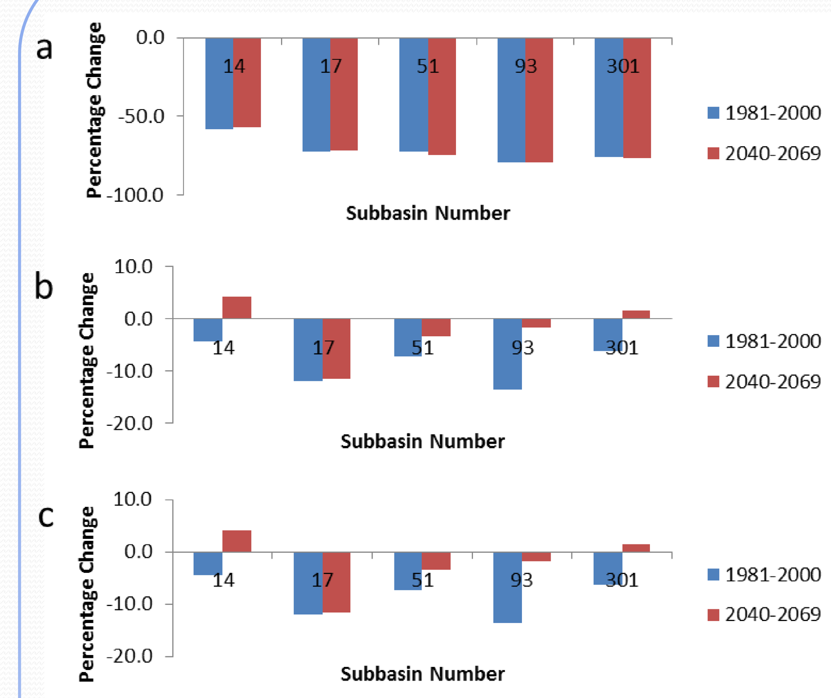

Figure 5. Percentage change in sediment (a), TN (b), and TP (c) yields under the baseline and 2040-2069 due to grassed waterway BMP.

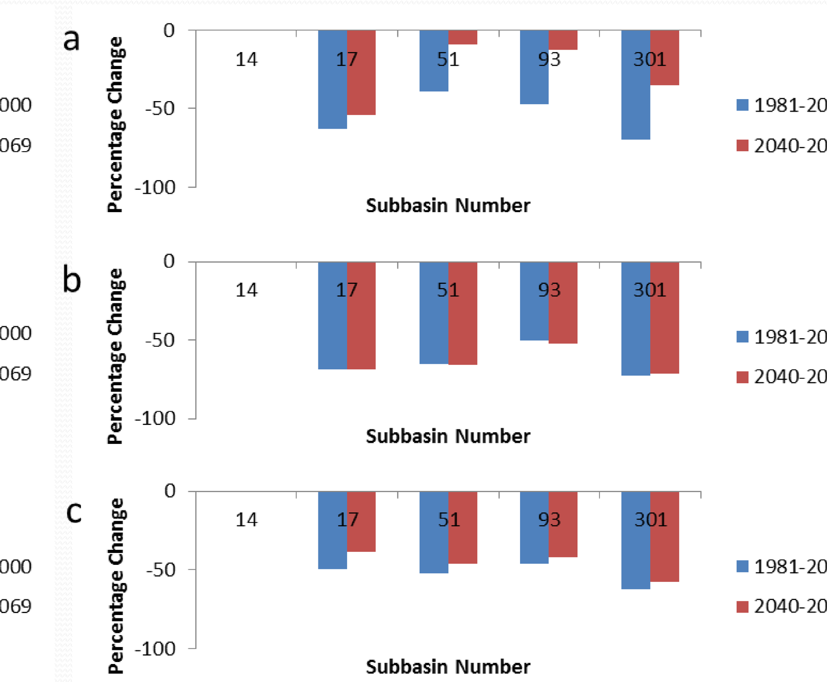

Figure 6. Percentage change in sediment (a), TN (b), and TP (c) yields under the baseline and 2040-2069 due to filter strip BMP.

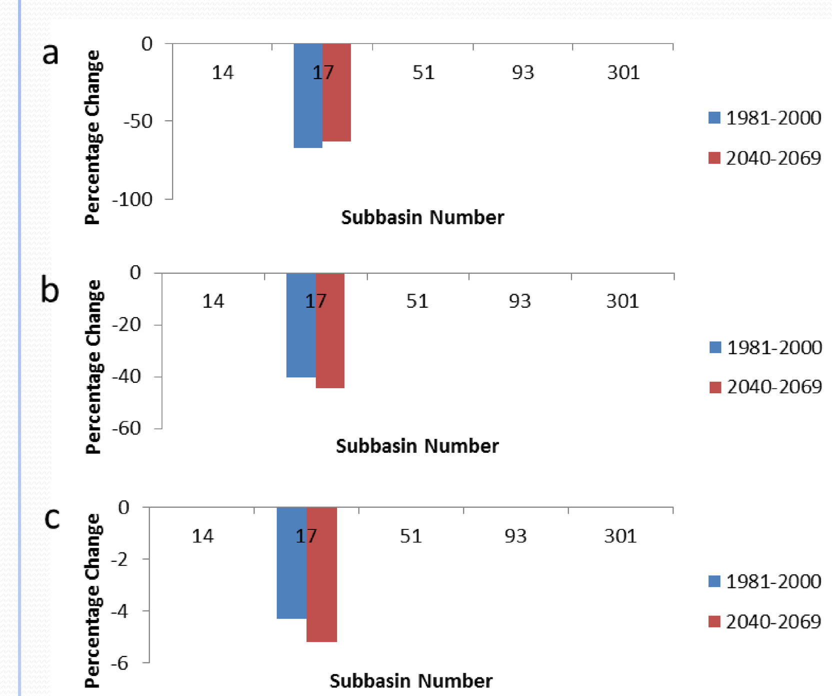

Figure 7. Percentage change in sediment (a), TN (b), and TP (c) yields under the baseline and 2040-2069 due to terrace BMP.

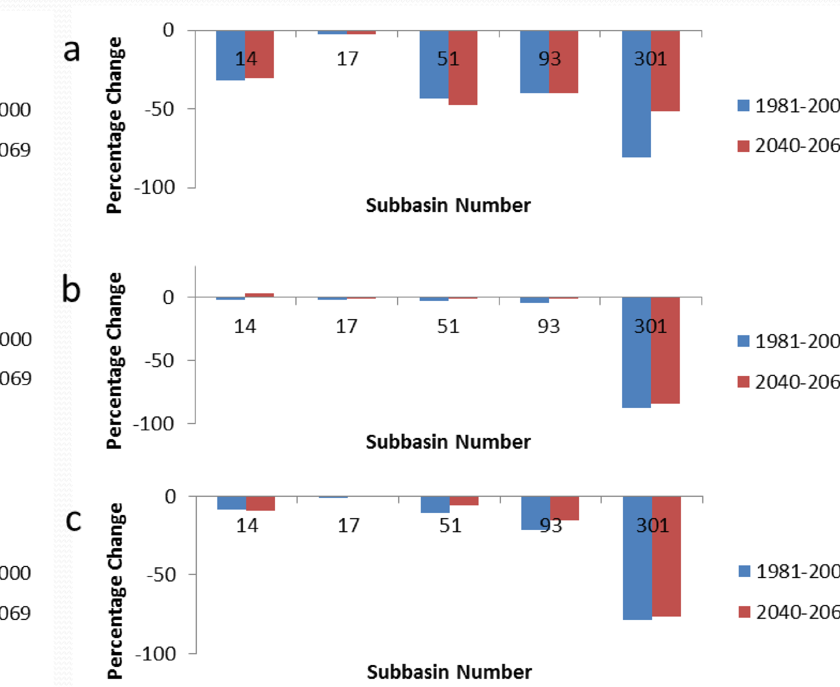

Figure 8. Percentage change in sediment (a), TN (b), and TP (c) yields under the baseline and 2040-2069 due to riparian buffer BMP.

Conclusions

- **Slight decreases in percentage reduction in nutrient yield due to BMPs in the period of 2040-2069 are likely because precipitation in the growing season is projected to decrease by 8% in the mid 21st century.**
- **Except for the terrace BMP which is only implemented at agricultural lands, the grassed waterway BMP is the most effective in reducing sediment yield, while the filter strip BMP can achieve the highest reduction in TN and TP output.**
- **The simulation results indicate that the pasture lands (subbasin 51, 93, 301) are sensitive to climate change and the type of BMPs implemented.**
- **This study indicates that BMPs can improve water quality by reducing sediment and nutrient entry into the Meramec River which will then help protect habitat for many riparian and aquatic species.**

References

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