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Impacts of Land Use Change on the Natural Flow Regime: A Case Study in the Meramec River Watershed in Eastern Missouri, USA

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Introduction

The natural flow regime of most rivers has been significantly altered by human activities. The natural flow regime within a watershed can be considered as the expected temporal patterns of streamflow variation in the absence of human impacts.

Land use change, including the development of agriculture and urbanization, is a primary cause of the loss of natural flow regimes. These changes have altered discharge volume, timing, and variability, and consequently affected the structure and functioning of river ecosystems.

A watershed model, the Soil and Water Assessment Tool (SWAT), was developed to simulate a long-term time series of streamflow within the Meramec River Basin in Missouri. An Indicator of Hydrologic Alteration (IHA) approach was applied to characterize the flow regime under the current land cover conditions as well as the simulated natural flow regime under the no land use change scenario.

This study provides a watershed-scale understanding of effects of land use change on a river's flow variability and provides a framework for the development of restoration plans for heavily altered watersheds.

Objectives

- To validate the SWAT model in terms of streamflow and sediment load for the Meramec River Basin in Missouri
- To evaluate the impacts of land use change on the natural flow regime

Materials and Methods

- The Meramec River Basin, covering an area of 10,270 km^2, is located in east central Missouri on the northeastern flank of the Salem Plateau (Fig. 1). Annual precipitation is about 1040 mm. The primary land uses are forest (68%), pasture (19%) and urban (8%).
- Tools: 1) *SWAT* (Arnold et al., 1998; Neitsch et al., 2011); 2) *IHA* was used for calculating a total of 67 statistical parameters: 33 IHA parameters, and 34 Environmental Flow Components (EFC) parameters (Richter et al., 1996,1997,1998; The Nature Conservancy, 2009).
- Study period is from January 1981 – 2014. Calibration: 1996-2012; Validation: 1981-1995, 2013-2014.
- SWAT inputs:1) Daily precipitation (10 stations) and 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).
- Calibrated variables: flow (8 stations) and sediment load (1 station)
- Model performance metrics: Coefficient of determination (R^2), Nash-Sutcliffe coefficient (NSE).
- Scenarios: Contemporary land use (baseline); Natural flow regime - exiting urbanization and agriculture converted to forest (hypothetical)

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 the streamflow (Fig. 2). 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.
- Results show average flow and sub-basin sediment outflow were decreased by 2% and 11%, respectively, under hypothetical scenario.
- Flow from sub-basins with high percent of agriculture area were increased under the hypothetic scenario (Fig 3). It is likely due to higher than pasture grass/agricultural plants runoff coefficient for the forest.
- Monthly average flow at tributary outlets and Meramec River outlet were decreased by 4% (Fig. 4).

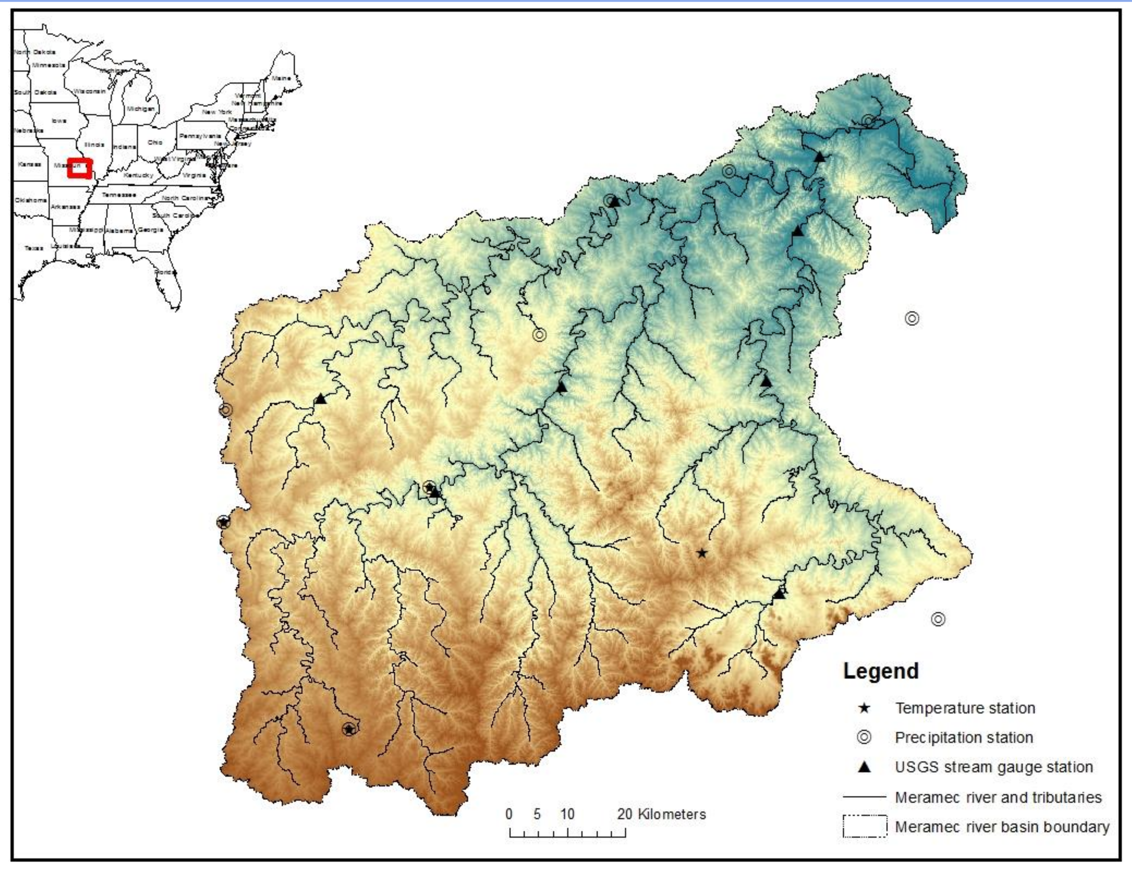

Figure 1. Locations of the Meramec River Basin, streamflow gauges, precipitation and temperature stations.

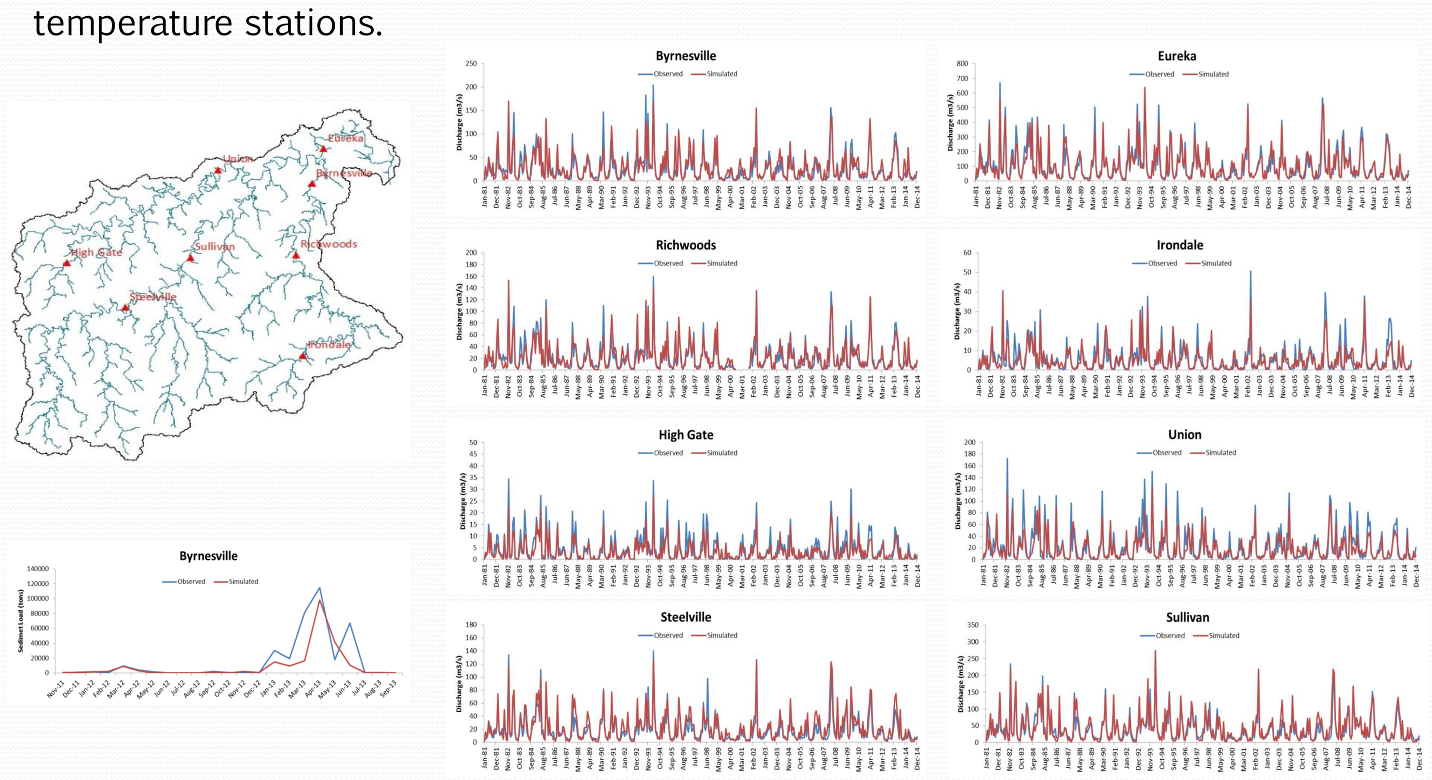

Figure 2. Calibration and validation of monthly streamflow and sediment load at the USGS stations in Meramec River Basin

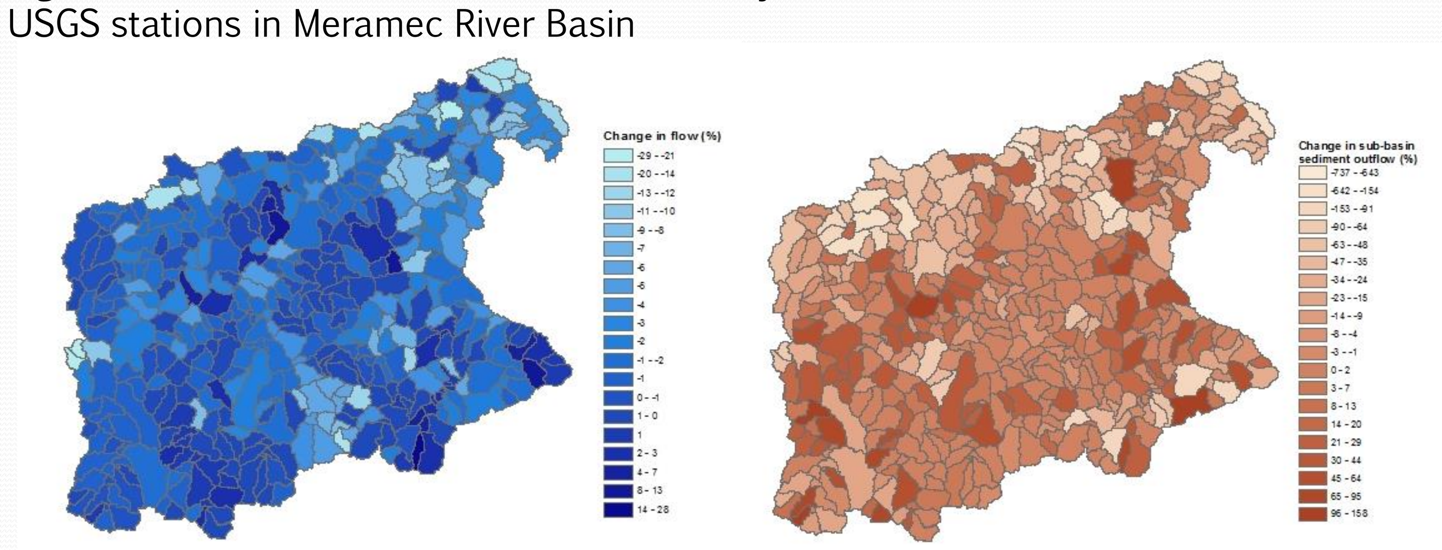

Figure 3. Percent difference in flow and sub-basin sediment outflows between baseline and hypothetic scenarios.

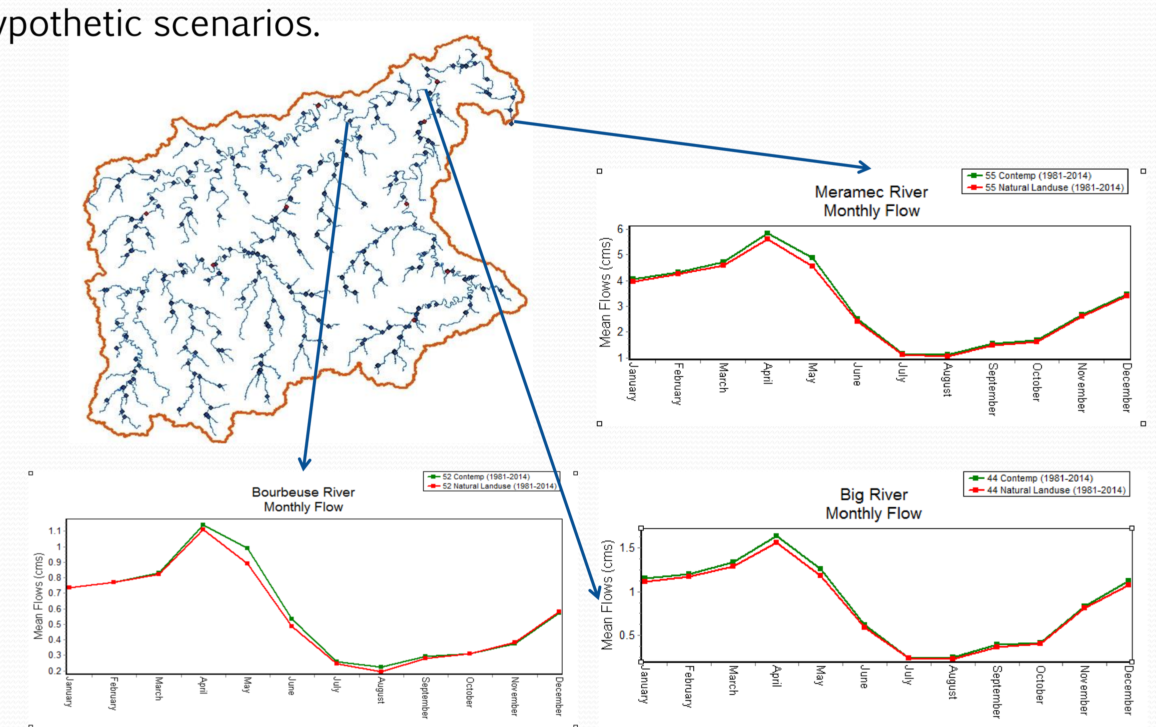

Figure 4. Averages of monthly flows for current condition and hypothetical scenario at the outlets of Meramec River Basin and main tributaries.

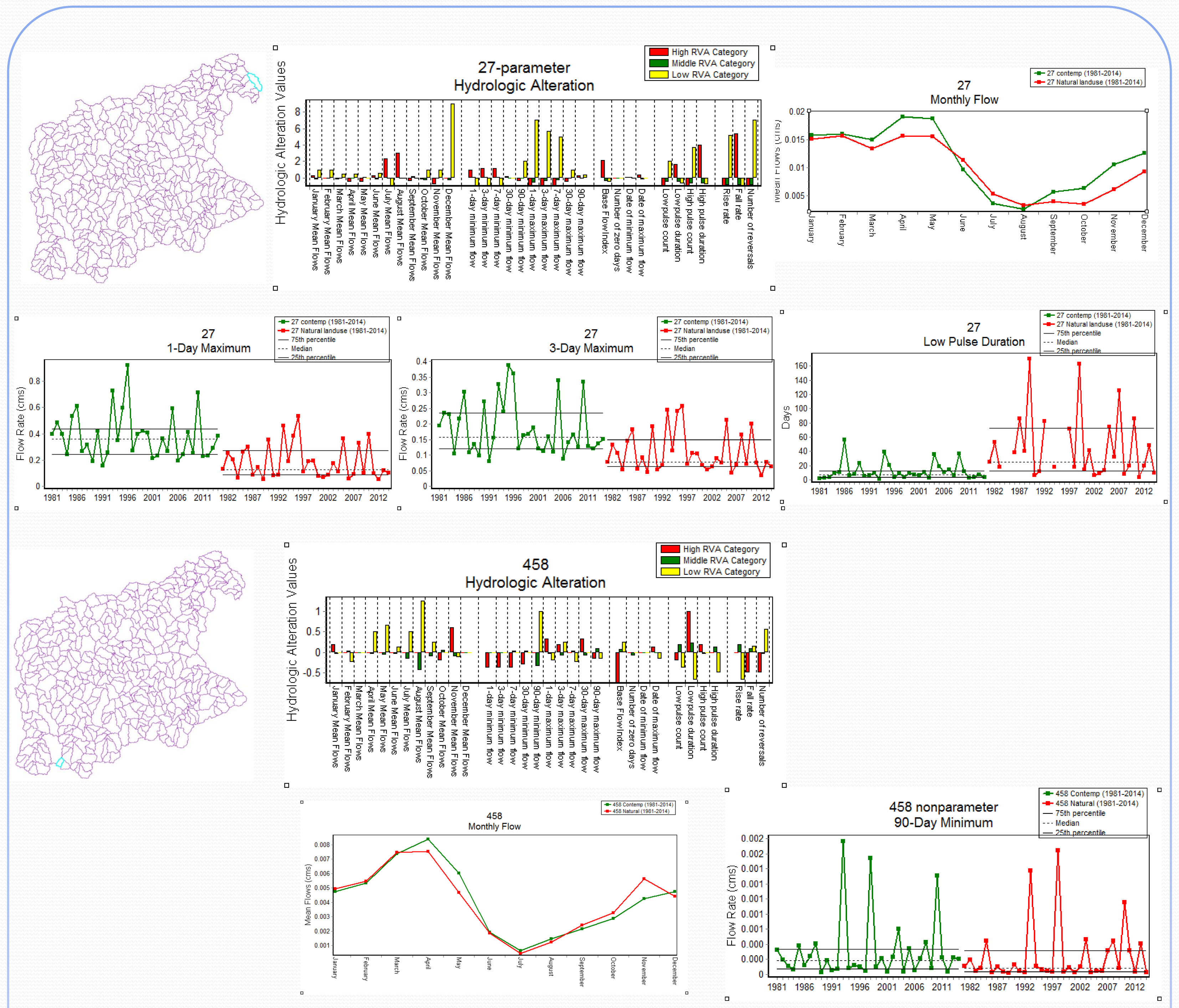

Figure 5. Changes in hydrologic alteration factors and the significantly altered factors at sub-basins with high percentage of urban (27) and agriculture (458) areas.

Conclusions

- Restoring current land cover to its natural state results in little to no changes in flow at outlets of main tributaries and Meramec River.
- Land use changes has greater impacts on flow and sediment in localized areas.
- Results clearly show changes in flow condition under natural flow regime at sub-basins with high percentage of land use being changed to urban and agriculture (Fig 5).
- The ecologically sensitive IHA parameters and the associated inferences that may be drawn regarding the impacts on aquatic species can be useful in cases where ecological data is limited.

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