Modeling Channel Response to Dam Removal in Lansing, Michigan, using SWAT

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Abstract

The removal of dams has increased in recent decades in the United States, largely resulting from decaying infrastructure and greater efforts to restore rivers to a more natural, free-flowing state. Dam removal presents the opportunity for increased public safety, improved environmental prosperity, and improved economic prosperity in conjunction with riverfront revitalization projects. The City of Lansing, Michigan, contains two moderate-to high-risk dams along the Grand River that pose a significant risk to the surrounding area in the event of structural failure.

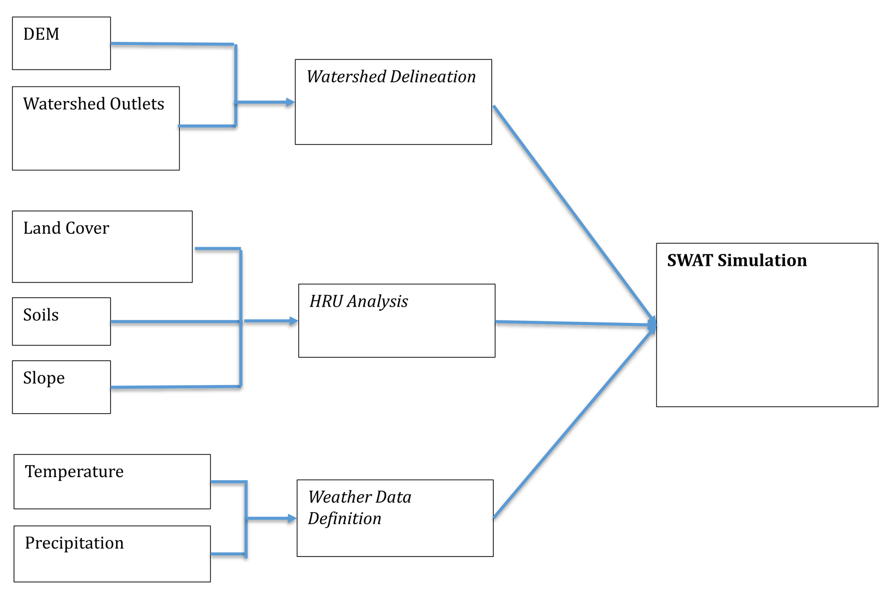
The Soil and Water Assessment Tool (SWAT) is applied to model the impacts of the Moores Park Dam and the North Lansing Dam on streamflow magnitude within downtown Lansing. The study used SWAT to recreate conditions in the Grand River watershed to approximate the differences in stream discharge with the dams in place and with the dams removed. It was hypothesized that removal of these structures will coincide with a decrease in stream discharge and downstream flooding concerns. Despite adjusting hydrologic parameters that effect the watershed, the model was unable to replicate baseline watershed conditions. Future research could be improved with more primary data collected in field studies.

Research Objectives

The primary purposes of this research were:

1) To effectively model baseline conditions in the Grand River Watershed;
2) To determine the difference in streamflow magnitude between baseline conditions and a "dam-out" scenario;
3) To relate modeling results to potential mitigation and management scenarios for the dams and surrounding area

Methodology



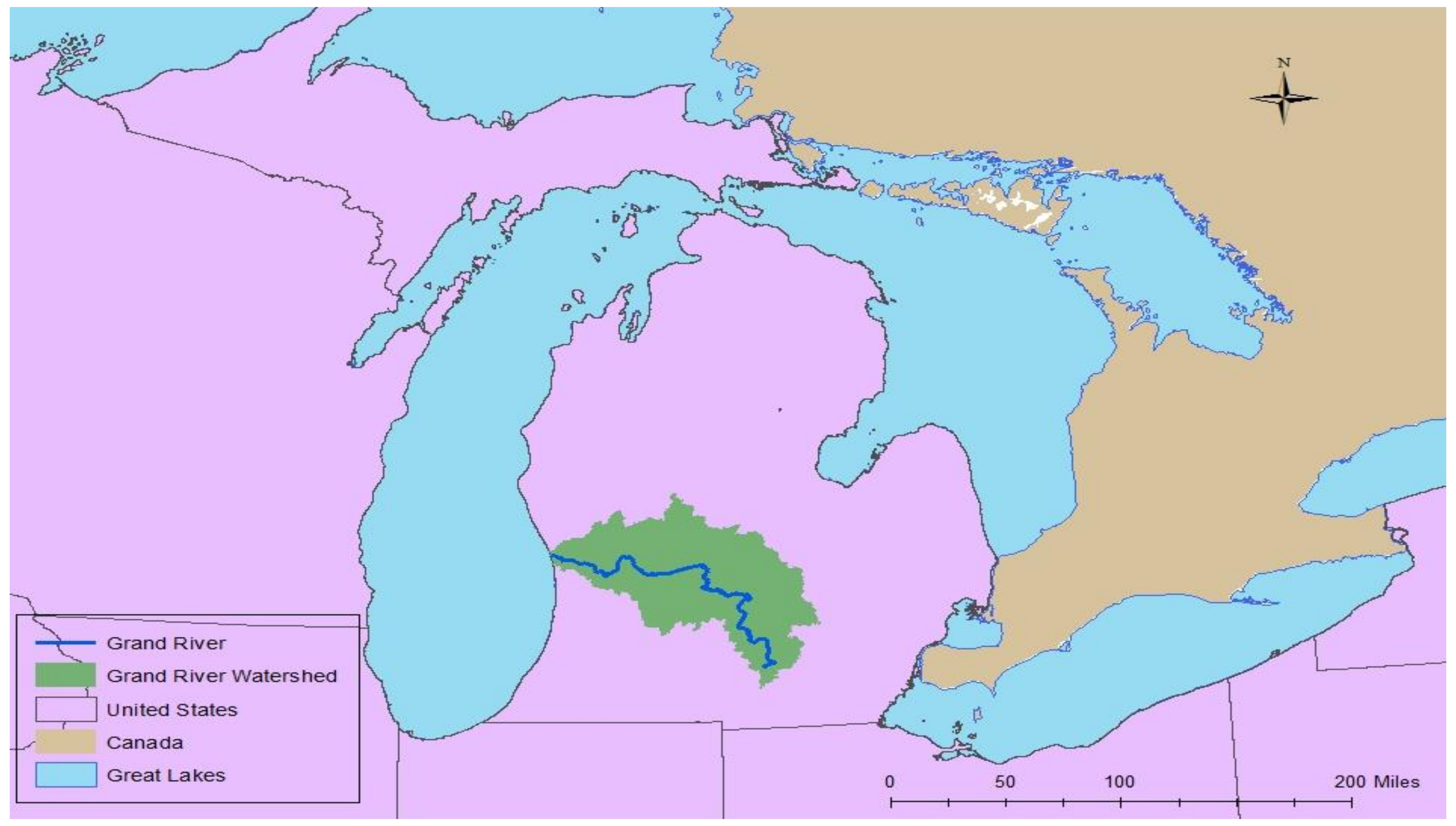
Modeling utilized the Soil and Water Assessment Tool (SWAT), developed a by the U.S. Department of Agriculture to analyze and predict impacts of land use practices and changes on watersheds (Gassman et al., 2007). The GIS interface for SWAT, called ArcSWAT, facilitated GIS data input into the model.

There are three main components to SWAT model construction: Watershed delineation, HRU Analysis, and Weather Data Definition. Watershed delineation involved setting the watershed boundary, importing an elevation profile, and defining watershed outlets. HRU analysis combined layers for land use/land cover, major soil types, and watershed slopes. HRUs represented modeled soil/land use/management combinations within a sub-watershed, and are represented as a percentage of the watershed area. Climate data were extracted from weather stations in the watershed from the Global Weather Data for SWAT website (Global Weather Data for SWAT, 2017). Attainable variables included temperature (°C), precipitation (mm), wind (m/s), relative humidity (percent), and solar radiation (MJ/m^2).

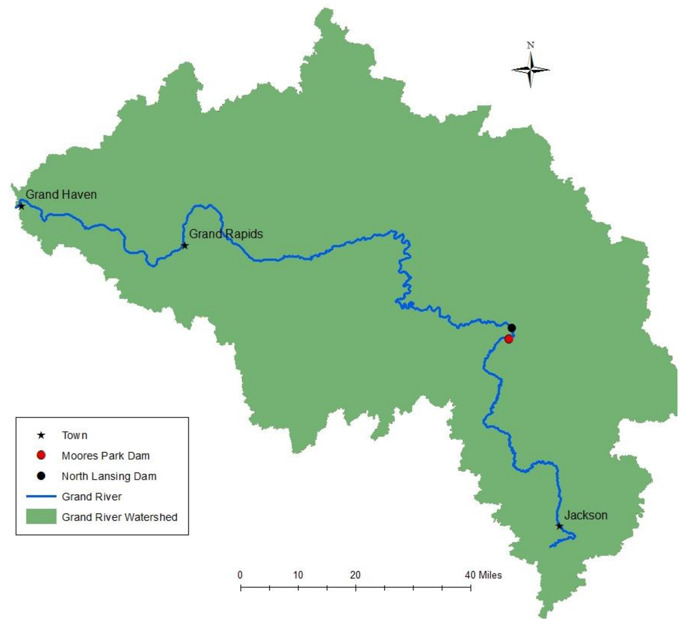
The input of impoundment characteristics is discussed within the SWAT Input/Output documentation (Arnold et al., 2012a). Impoundment characteristics may be input as a reservoir or pond depending on the location of the dam with respect to the main channel or other channels, and the size of the impoundment. I chose to simulate the study dams in the watershed as reservoirs.

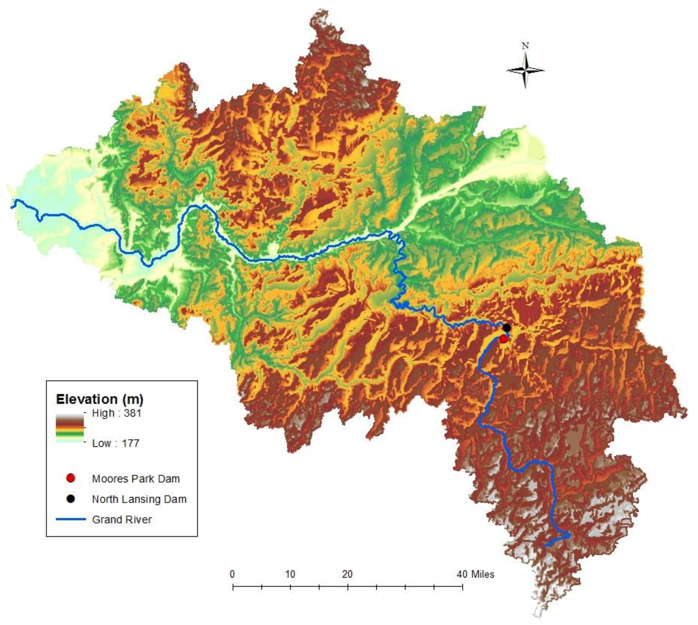
The calibration and validation of the model compared simulated discharge values to observed discharge values for the Lansing USGS gauging station. A local sensitivity analysis preceded SWAT calibration and validation. This process identified the rate of change in model output because of model inputs, or parameters (Arnold et al., 2012b). This was done using the Manual Calibration Helper window in SWAT, which allows for multiplying a parameter by a threshold, adding to a parameter by a threshold, or replacement of the parameter value.

Study Area

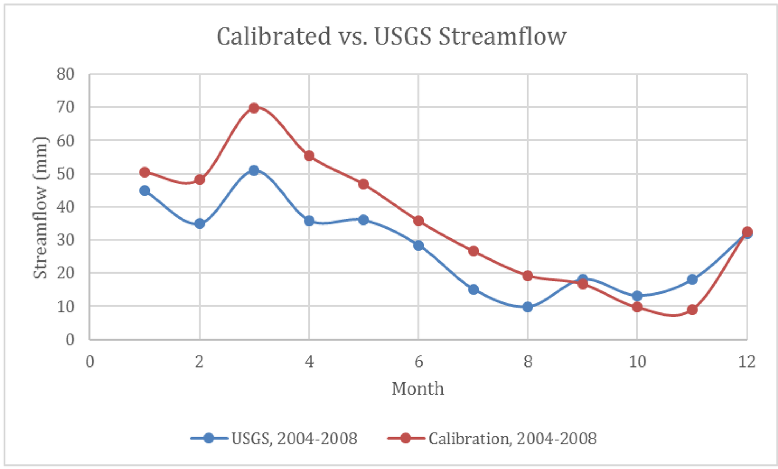


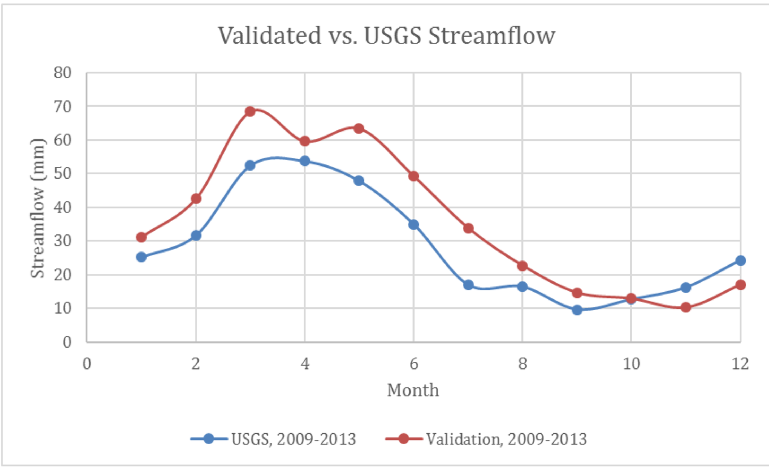
The Grand River is the longest river in Michigan, draining lands from Jackson to Grand Haven. There are 231 dams within the watershed, of which 30% were constructed prior to 1960 and have outlived their function ability. Of these 231 impoundments, 27 are classified as high-risk structures and eight are classified as hazard type 1 dams, meaning failure would result in the loss of life. The Moores Park Dam is assessed a hazard type 1 rating, while the North Lansing Dam has not been assessed a hazard rating (Hanshue & Harrington, 2011).





Dams-In Results



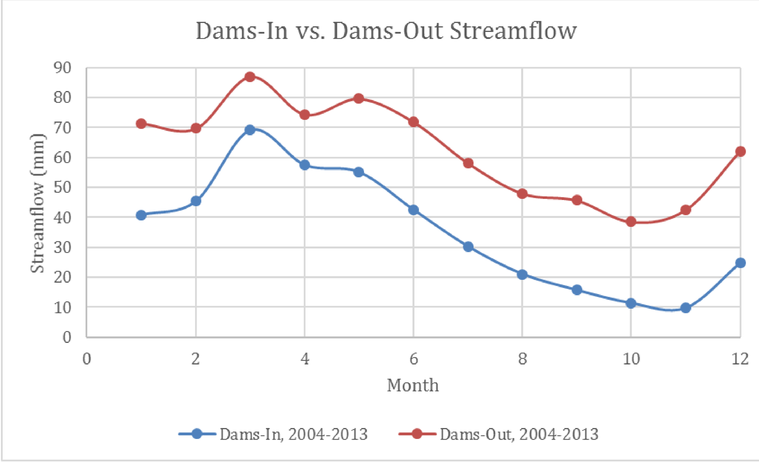


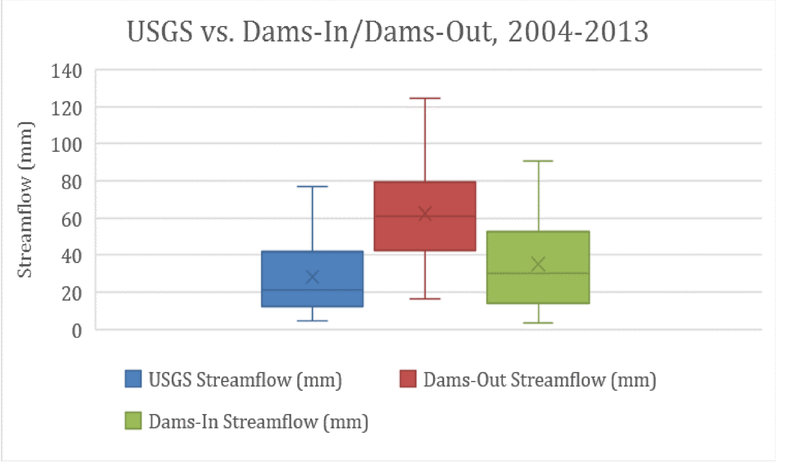
Scenario	Std. Dev.	R^2	NSE	RMSE	MAE	PBIAS
Calibration – Dams-In	23.848	0.854	-30.755	16.186	12.743	-35.233
Validation – Dams-In	24.950	0.880	-34.955	16.309	11.721	-34.933

Calibration	R^2	NSE	PBIAS
Winter	0.719	0.005	-33.251
Spring	0.8	-119.937	-52.267
Summer	0.008	-0.234	-72.247
Fall	0.923	-2.853	16.833

Validation	R^2	NSE	PBIAS
Winter	0.995	-112.359	-35.466
Spring	0.705	-20.747	-39.384
Summer	0.723	-6.247	-81.466
Fall	0.581	-0.466	16.585

Dams-Out Results





Scenario	Mean	Std. Dev.	R^2
Dams-In	35.245	24.304	0.936
Dams-Out	62.435	24.041	

Scenario	Mean	Std. Dev.	R^2
USGS	28.306	18.870	0.898
Dams-Out	62.435	24.041	

Research Implications

Despite difficulty in accurately representing conditions in the Grand River Watershed, SWAT remains a versatile and practical software in hydrological modeling applications. SWAT, in conjunction with ArcGIS, could store and compute a large volume of raster and vector data from varying sources. The software is relatively user-friendly, and the SWAT Input/Output documentation (Arnold et al., 2012a) thoroughly outlines model components, variables, and file information.

This research demonstrates the ongoing need to improve hydrological modeling for heavily impounded watersheds. While the dams-out scenario predicted a sharp increase in mean monthly streamflow, the calibration/validation results were not statistically significant. However, this potential increase in streamflow may be confirmed if the City of Lansing or Michigan Department of Natural Resources continued SWAT calibration of the watershed with improved sediment, water quality, and reservoir data.

While baseline conditions were modeled with statistical significance during individual seasons, collective yearly results were not accurate. Therefore, conclusions regarding the increase in streamflow between a dams-in and dams-out scenario may not reject the null hypothesis if the study were to be further calibrated for sediment and water quality.

Despite broad difficulties in producing a statistically significant model, Lansing city officials should still consider dam removal as the best mitigation measure for these aging structures. Further model calibration may demonstrate that the projected increase in streamflow in a dams-out scenario is viable and warrants proactive measures. Dam removal would likely necessitate fortifying levees along the Grand River, but would also reduce the risk of significant property damage and loss of life from structural failure.

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