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Implications of Dam Removal: Modeling Streamflow in Lansing, Michigan Using the Soil and Water Assessment Tool

Ryan J. Filbin
University of Wisconsin-Milwaukee, rfilbin@uwm.edu

Laiyin Zhu
Western Michigan University

Lisa DeChano-Cook
Western Michigan University

Lei Meng
Western Michigan University

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Abstract

This paper uses hydrologic modeling methods to determine the effects of dam removal in Lansing, Michigan, on the streamflow of the Grand River, flooding risks, and flood mitigation strategies. In Michigan, more than one-half of the state's dam infrastructure is more than 50 years old, and more than one-third are classified as having a moderate-to high-risk potential. Lansing, Michigan, contains two moderate-to high-risk dams along the Grand River that are a significant hazard to the surrounding community in the event of structural failure. This research utilizes the Soil and Water Assessment Tool (SWAT) to model the impacts of the Moores Park Dam and the North Lansing Dam on streamflow in the greater Lansing area. The purpose of using SWAT was to represent baseline streamflow conditions in the Grand River, compare the differences in streamflow magnitude between baseline conditions and a "dam-out" environment, and interpret the implications of modeling results for mitigation and management strategies in the study area. Our model exhibited similar streamflow patterns to USGS historical data, with overestimation errors during calibration and validation stemming from groundwater infiltration inaccuracies. The dams-out model for streamflow was higher than the baseline model for streamflow; however, both model iterations require further calibration and validation for the magnitude differences to be considered statistically significant. Despite issues of model calibration and validation, and ongoing model adjustments for accurately representing heavily impounded watershed, the results of this study provide a template for the City of Lansing to adapt their flood mitigation strategies in the study area and further calibrate SWAT with improved sediment, nutrient, and dam attribute data.

Keywords

Dam removal, Watershed modeling, SWAT, Grand River, Watershed management

1 INTRODUCTION

Dam building and dam infrastructure are vital to increase economic productivity and viability for many global regions. The geologic setting of the site, mechanisms and magnitude of sediment transport, channel processes, and disturbances drive the response of a river and watershed to impoundment (Grant et al. 2003). Dams serve as barriers that impact downstream streamflow conditions and sediment transport, causing a change in thermal regimes and the function of riparian and aquatic habitats (Poff and Hart 2002).

Dam removal may yield improved ecological health and natural river restoration but may also disrupt the current equilibrium surrounding the site (Grabowski et al. 2018). The removal of the Dead Lake Dam (Florida), Edwards Dam (Maine), and Elwha Dam (Washington) yielded improvements in spawning grounds for fish, fish passage, sediment transport, and water quality (Bednarek 2001). Other removal efforts with the Fort Edwards Dam (New York) and Fulton Dam (Wisconsin) have negatively impacts ecology through changes in the thermal regimes and community composition within the ecosystem, the loss of reservoir species, and the release of toxic polychlorinated biphenyls downstream from the dam site (Bednarek 2001).

Multivariate models are utilized to model the response of a river to the presence of a dam. The Indicators of Hydrologic Alteration model has found impoundments to reduce the discharge of 1-day flows most severely, with a less pronounced effect on 90-day flows, indicating that the impact on flow becomes more consistent with increased flow duration (Magilligan and Nislow 2005). The Spatially Explicit Delivery Model was implemented for four aging dams on the Kalamazoo River between Allegan and Plainwell, Michigan. Sediment transport simulations reflected a dynamic equilibrium state, and the absence of dams would lower the channel head, promoting further stream erosion and sediment transport (Syed et al. 2005). A study of an 8.8 km reach of the Kalamazoo River between Plainwell and Otsego, MI, where two low-head dams are being evaluated for removal by the state of Michigan, offered several options for the assessment of outcomes related to dam removal (Wells et al. 2007). A stretch of the Kalamazoo River between Plainwell and Otsego, Michigan, was evaluated for erosion, transport, and deposition of sediments over a 17.7-year period using the CONCEPTS model. Under a dams-out scenario, bed erosion and sediment transport would greatly increase, headlined by a 187% increase in average annual sediment load (Wells et al. 2007).

The Soil and Water Assessment Tool (SWAT) provides one of the best approaches for modeling changes in hydrological basins. This software was developed by the United States Department of Agriculture (USDA) to analyze and predict impacts of land use practices and changes on watersheds (Gassman et al. 2007). A study of the Huron and Raisin River watersheds of southeast Michigan used SWAT to analyze the influence of impoundments, including for stream nutrient transport (Bosch 2008). Both cases showed an increase in nitrogen and phosphorus loads in the absence of impoundments, with the most noticeable change near river mouths or high runoff source areas. More specifically, the Raisin River watershed model underpredicted discharge against daily and monthly records, while the Huron River watershed model overpredicted monthly discharge and underpredicted daily discharge. Furthermore, simulated stream flow during the validation period was consistently overpredicted during the summer; when flow magnitudes are typically lower (Bosch 2008).

Recent SWAT literature has emerged assessing the impacts of dams on sediment inflow into reservoirs, changing flood frequency conditions from new dams, and changing natural flows resulting from hydropower development (Djebou 2018; Lee et al. 2017, Wang et al. 2018). Further empirical contributions to hydrologic modeling and the cumulative impacts of impoundments are critical to address interdisciplinary gaps in the science of dam removal (Grabowski et al. 2018).

The Moores Park and North Lansing Dams are deteriorating structures presenting a threat to the downtown Lansing area. These dams are identified as significant risks because of the potential impacts if they were to fail, not necessarily because of the respective structural integrities (Dam Failure n.d.). This research uses SWAT to simulate stream flow without the presence of the Moores Park and North Lansing Dams along the Grand River to evaluate changes in streamflow and flooding risks. The study contributes to potential mitigation and planning strategies for the riverfront area in Lansing as the dams are evaluated for future removal. The purposes of this research are: (1) to model baseline conditions in the Grand River Watershed, (2) to determine the difference in streamflow magnitude between baseline conditions and a "dam-out" scenario; and (3) to relate modeling results to potential mitigation and management strategies for the dams and surrounding area.

The null hypothesis for this study was no significant change in streamflow magnitude and flooding risk with the dams in-place versus the dams not in-place. Based on a Draft Grand River Assessment by Hanshue and Harrington (2011), we expected a decrease in stream flow magnitude and a decrease in flooding risks.

2 MATERIAL AND METHODS

2.1 Study Area

The Grand River is the longest river in Michigan (260 km), and the watershed is the second largest in the state (14,431 km^2). The river drains portions of 15 counties from its headwaters near Jackson to its terminus in Grand Haven. The land use for the watershed is shown in Figure 1, using the United States Geological Survey (USGS) Land Cover Institute's National Land Cover Database (NLCD) for 2011. Southern Michigan has a continental climate pattern with an average annual precipitation of 86 centimeters and average annual snowfall of roughly 101 centimeters (Hanshue and Harrington 2011). The location of the watershed with respect to the Great Lakes region is shown in Figure 2.

The USGS attributes uncertainty in discharge-frequency estimates to fluctuations in soil permeability, channel slope, and mean annual precipitation in the watershed (Perry, 2008). The flow pattern of the Grand River varies seasonally, yet predictably. Flows of greater magnitude correspond to heavier spring and early summer precipitation with saturated soils and snowmelt, along with seasonal fall rains and plants ceasing transpiration processes. Flows of lower magnitude correspond to lessening precipitation in late summer and less winter infiltration and runoff with precipitation stored as snow and ice (Hanshue and Harrington 2011).

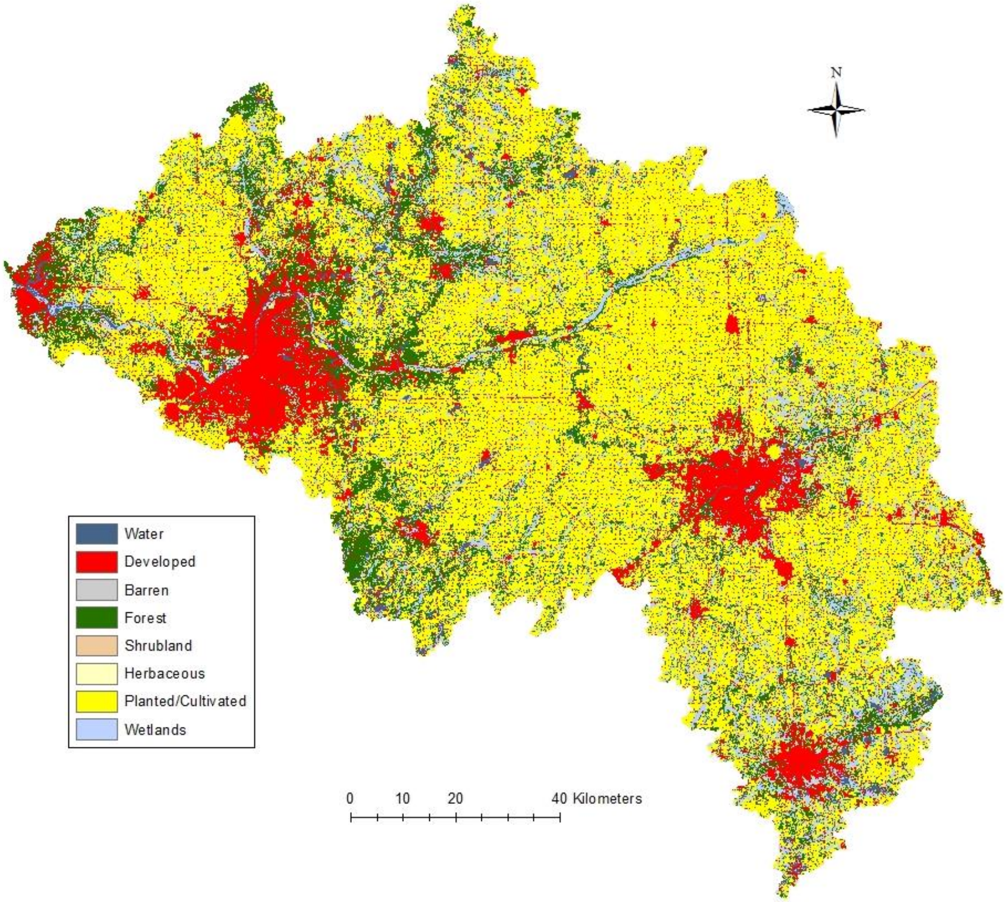

Figure 1. Grand River watershed land use, 2011.

The US Army Corps of Engineers lists 941 Michigan dams in its National Dam Inventory Report. Of these 941 dams, 322 are classified as having a moderate-to high-risk potential. Several dams along the Grand River have a high hazard potential because major structural failure would result in major property damage and/or the loss of life (Hanshue and Harrington 2011). Including the Moores Park Dam and North Lansing Dam, 30 percent of the 231 dams in the watershed were constructed prior to 1960 and have outlived their function ability (Hanshue and Harrington 2011). The relative locations of the researched dams in respect to the Grand River Watershed are shown in Figure 2.

2.2 Model Setup

Modeling utilized ArcSWAT utilities within ESRI ArcGIS. Part of the utility of SWAT is its ability to account for land use changed through time (Arnold et al. 1998). Bosch (2008) outlines the methods for calibrating SWAT for a watershed. There are three main components to SWAT model setup: Watershed delineation, Hydrologic Response Unit (HRU) Analysis, and Weather Data Definition. Watershed delineation involved setting the watershed boundary, importing an elevation profile, and defining watershed outlets. Watershed boundary data were available via the HUC-8 sub-watershed boundaries provided by the USDA. The Digital Elevation Model (DEM) for Michigan was obtained from the Michigan Center for Geographic Information (MiCGI). Watershed outlets were defined in ArcSWAT through DEM analysis.

Figure 2. Locator map of the Grand River watershed.

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. For ArcSWAT, sub-watershed delineation was utilized to divide the watershed based on topographic features. Land cover data (30-meter spatial resolution) was obtained from the USGS NLCD 2011 data. Soil data were available for Michigan through the MiCGI. Slope data for the watershed were derived from the watershed DEM in ArcGIS. Climate data were extracted from weather stations in the watershed from the Global Weather Data for SWAT website (Global Weather Data for SWAT 2017). Variables of interest included temperature (°C), precipitation (mm), wind (m/s), relative humidity (percent), and solar radiation (MJ/m^2).

The model setup initially involved delineating the watershed using Automatic Watershed Delineation. The DEM (90-meter resolution) for the watershed was analyzed to estimate the flow direction and flow accumulation of the watershed stream network. Following this, the model required information for the minimum area of each HRU in the watershed to create the stream network and outlets. We selected 3572 hectares per HRU as the optimal minimum size to depict the frequency and extent of streams in the watershed. Once the stream network was created, watershed outlets were defined. We manually added watershed outlets for the Moores Park and North Lansing Dams, along with all other dams in the upper reaches of the catchment. This was important because the SWAT program will only allow for placement of the dams and reservoirs at HRU outlets or user-defined outlets. The USGS stream gauge at Lansing was selected as the whole watershed outlet, as all flows that contribute to the dam study area also contribute to this location. The final steps in the Automatic Watershed Delineation were to delineate the watershed, calculate subbasin parameters, and manually add reservoirs to represent dam locations. A total of eight reservoirs were added to the basin at the user-defined subbasin outlets.

Land use, soils, and slope definitions were reclassified using HRU Analysis. The process divided the watershed into unique sub-watersheds that contribute to the overall flow of water in the system. HRU Analysis confirmed that the delineated watershed is dominated by agriculture uses and wetlands, with low slope gradients and variations in topography.

The last step before SWAT calibration was creating database input tables for weather, soil, water use, groundwater, channel, management, and configuration files. Following this, the preliminary SWAT iteration ran from January 1, 2000, until December 31, 2013. The first four years were used as the recommended warm-up period for the model.

2.3 Model Calibration and Validation

Local sensitivity analysis involved the manipulation of values individually (Arnold et al. 2012b). This was done using Manual Calibration, which allows for multiplying a parameter by a threshold, adding to a parameter by a threshold, or replacement of the parameter value (Arnold et al. 2012a). Initial model iterations significantly overestimated water depth (discharge) at the watershed outlet and overestimated the ratio of surface flow to baseflow into the stream channel. Streams in south-central Michigan typically have a baseflow index of 50-70% (Santhi et al. 2008). Adjustments made during sensitivity analysis are described in Table 1.

Monthly average streamflow data were applied during calibration and validation. These data were available from the USGS. The USGS maintains 21 stream gauges in this watershed, offering varying data availability, data coverage, and temporal span of records. The primary location of concern for stream discharge was Lansing since this location is downstream of both dams and is the whole watershed outlet of the delineated watershed.

Table 1. Parameter adjustments for manual calibration.

Parameter	SWAT Range	Substituted Value	Land Use
ALPHA_BF	0-1	0.1	All
Cn2	10-90	55	AGRR, FRSD
Cn2	10-90	60	HAY
Cn2	10-90	65	UIDU, URHD, URLD, URMD, WETN
Cn2	10-90	62	WETF
ESCO	0-1	0.1	All
GWQMN	0-5000	200	All
GW_REVAP	0.02-0.20	0.20	All
Rchrg_dp	0-1	0.5	All
SOL_AWC	0.1-0.2	0.15	All

Calibration of the "dam-in" scenario used data from January 1, 2004, to December 31, 2008, and validation of the "dam-in" scenario used data from January 1, 2009, to December 31, 2013. This duration was selected with consideration of the complete weather and stream flow records available, and to generate a model more correlated with modern land use/land cover within the watershed.

The significance of the model results was determined based on statistical goodness of fit. Simulation evaluation metrics included standard deviation, Pearson's correlation coefficient (R), Nash-Sutcliffe efficiency (NSE), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Percent Bias (PBIAS). Significance of model parameters follows the guidelines of previous SWAT and hydrologic modeling literature (Moriasi et al. 2007; Santhi et al. 2001; Willmott and Matsuura 2005).

3 RESULTS

3.1 Scenario One – Dams-In

The methodology was implemented for two scenarios – one with the Moores Park and North Lansing Dams in place (dams-in), and one with the dams not in place (dams-out). SWAT simulations were performed with the same hydrological parameter adjustments, period, and geospatial data in each case. The model was only calibrated and validated for the Dams-In simulation.

A comparison of the observed and calibrated water depth values is shown in Figure 3. The model accounted for 419 mm of the 337 mm of the annual discharge at the USGS gauge in Lansing, yielding an overprediction of roughly 25%. A comparison of the observed and validated water depth values is shown Figure 4. The model accounted for 426 mm of the 342 mm of the annual discharge at the USGS gauge in Lansing, yielding an overprediction of roughly 25%.

Simulated and observed stream data exhibit similar trends throughout the year. The model overestimates higher flow events during peak flooding from January through May, and underestimates lower flow events in late fall and early winter (October-December). The model outputs for calibration and validation also have a greater range than the observed data. The standard deviation for calibration and validation are rather similar, indicating a similar dispersion of streamflow for individual months (Table 2).

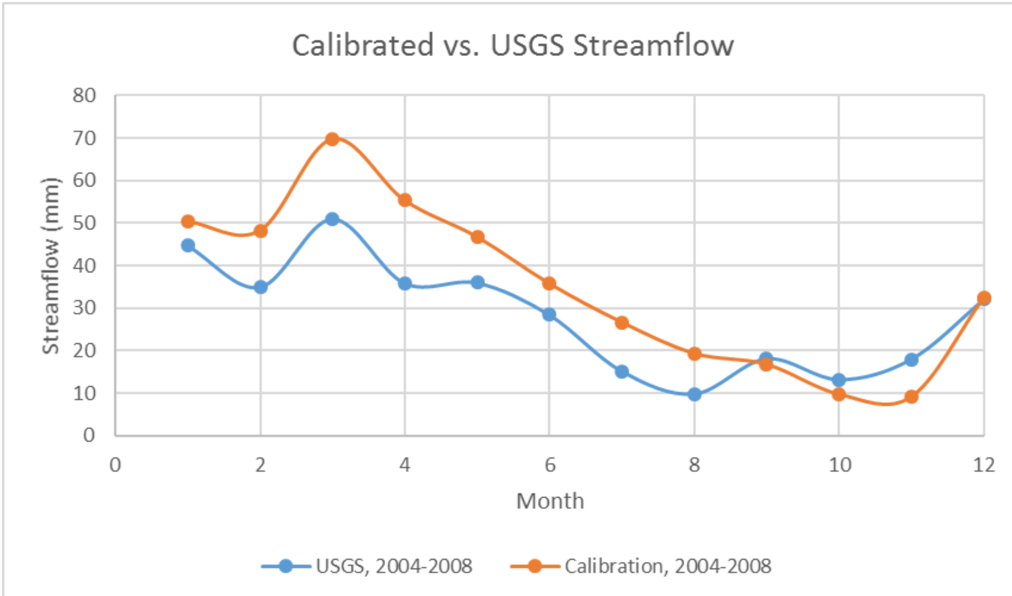

Figure 3. Graph of observed streamflow and dams-in calibrated streamflow outputs.

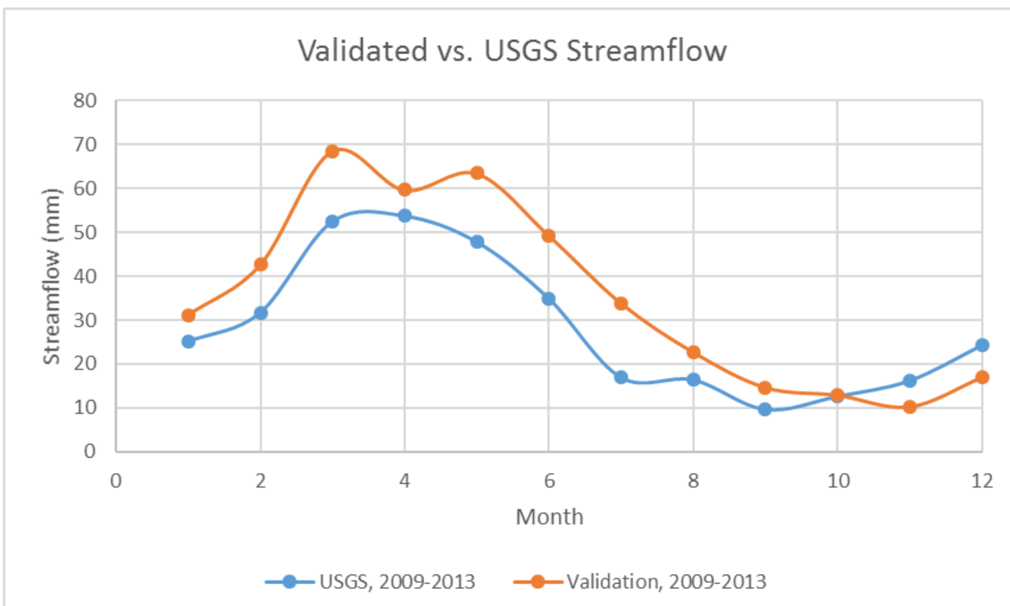

Figure 4. Graph of observed streamflow and dams-in validated streamflow outputs.

Pearson's correlation coefficient was found for the correlation between calibrated streamflow and observed streamflow, based on monthly flow data (Table 2). The analysis indicated a strong correlation. Simulated higher and lower flow months tended to correspond well with observations. The Nash-Sutcliffe Efficiency compared the relationships between calibrated data and observed data, and between validated data and observed data (Table 2). In both scenarios, the NSE statistic fell within the general accepted range of values but just beyond the preferred range for SWAT simulations, indicating moderate statistical significance. The Root Mean Square Error (RMSE) was estimated for amount of error associated with both calibrated and validated streamflow (Table 2). They are similar, which indicates considerable uncertainty in predicting the streamflow over the course of the year. While RMSE is an effective measure of model uncertainty, it is skewed by large error magnitudes in predicted data. The magnitude of errors associated with calibrated and validated data was also determined using Mean Absolute Error (MAE, Table 2). The MAE values for the calibration and validation scenarios are similar, indicating noticeable variance of the frequency distribution of error magnitudes. A Percent Bias statistic determined the average tendency of calibrated and validated data as compared with observed data (Table 2). In each scenario, a negative PBIAS value was derived, meaning that calibrated and validated data were overpredicted by roughly 25%.

Table 2. Dams-In calibration and validation statistics.

Scenario	Standard deviation	R	NSE	RMSE	MAE (mm)	PBIAS (%)
Calibration – Dams-In	23.848	0.786	0.141	16.186	12.743	-24.475
Validation – Dams-In	24.950	0.803	0.337	16.309	11.721	-25.555

We calculated calibration and validation statistics in Table 3 and Table 4 to separate data into the four seasons. The grouping of months is: *Winter*: December-February; *Spring*: March-May; *Summer*: June-August; and *Fall*: September-November. These groupings reflect meteorological seasonality and conventional seasonal grouping in hydrologic modeling literature (Blandford et al. 2008; Wang et al. 2018). Pearson's correlation coefficient was found for the correlation between calibrated streamflow and observed streamflow for each season (Table 3). The analysis indicated a strong correlation for each season, except for the summer. During the summer, the model significantly overpredicted streamflow in July but only marginally overpredicted streamflow in August, despite both months having a similar average streamflow. During the fall, the model nearly predicted the average streamflow for December, and underpredicted the average streamflow for October and November. Pearson's correlation coefficient was also determined between validated streamflow and observed streamflow for each season (Table 3). It indicated a strong correlation for each season, except for the fall. During the fall, the model nearly predicted the average streamflow for October, and underpredicted the average streamflow for November and December. During the winter, the model overpredicted average streamflow by roughly 130%.

The Nash-Sutcliffe Efficiency compared the relationships between calibrated data and observed data for each season (Table 3). The best statistical significance was found for the summer, while NSE values for winter and fall were positive and close to 0, indicating that model predictions for average streamflow were roughly as accurate as predictions based on the observed monthly average. The spring NSE value (Table 3) was negative and skewed the yearly NSE value (Table 2), as individual spring months had large overestimations of average monthly streamflow. The NSE also compared the relationships between validated data and observed data for each season (Table 3). The fall NSE value fell within the preferred range for SWAT simulations, while values for spring and summer also exhibited moderate statistical significance. The winter NSE value (Table 3) skewed the yearly NSE value (Table 2) as individual winter months had large overestimations of average monthly streamflow.

Table 3. Seasonal calibration and validation statistics.

Scenario	Season	R	NSE	PBIAS (%)
Calibration	Winter	0.731	0.004	-17.200
	Spring	0.609	-0.107	-39.705
	Summer	0.751	0.145	-52.986
	Fall	0.663	0.629	27.896
Validation	Winter	0.640	-0.209	-11.871
	Spring	0.605	0.539	-24.294
	Summer	0.669	-0.449	-55.010
	Fall	0.324	0.861	1.740

Percent Bias determined the average tendency of calibrated data as compared with observed data for each season (Table 3). In every season besides the fall, a negative PBIAS value was derived, meaning that calibrated data were overpredicted. The positive PBIAS value in the fall indicates that the model underpredicted average monthly streamflow. PBIAS is also determined to compare the average tendency of validated data with observed data for each season (Table 3). A negative PBIAS value was derived for each season besides the fall, meaning that calibrated data were overpredicted. The positive PBIAS value in the fall indicates that the model underpredicted average monthly streamflow. In both the calibration and validation scenarios, the magnitude of the PBIAS value was highest during the summer, indicating more severe overprediction of average monthly streamflow.

3.2 Scenario Two – Dams-Out

In the Dams-Out scenario, the same input data, hydrological parameters, and simulation timeframe were used in SWAT. The only changes from the Dams-In scenario were not including data for the Moores Park and North Lansing Dams, and not calibrating or validating the model results. The Dams-In and Dams-Out water depth values is shown in Figure 5. The dams-out model accounted for an annual discharge of 749 mm, or a 77.1% increase in annual discharge over the dams-in value of 423 mm. The Dams-Out scenario appeared to overestimate higher flow events more than the Dams-In scenario during peak flooding season from January through May. The Dams-Out and Dams-In scenarios both have a larger range of data than the observed data.

The standard deviation for Dams-In and Dams-Out was rather similar, indicating a similar dispersion of streamflow for individual months. However, the average monthly streamflow for Dams-Out was nearly double the average monthly streamflow for Dams-In, indicating a significant increase in average streamflow at the Lansing gauge with the Moores Park and North Lansing Dams removed.

Table 4. Observed and modeled statistics. Font style indicates statistical groupings of data.

Scenario	Mean	Standard deviation	R
Dams-In	*35.245*	*24.304*	*0.880*
Dams-Out	*62.435*	*24.041*	
USGS	28.306	18.870	0.797
Dams-Out	62.435	24.041	

Pearson's correlation coefficient was found for the correlation between Dams-In streamflow and Dams-Out streamflow, indicating a strong correlation (Table 4). Dams-Out higher flow months tended to correlate with Dams-In higher flow months, while Dams-Out lower flow months corresponded with Dams-In lower flow months. Pearson's correlation coefficient was found for the correlation between USGS streamflow and Dams-Out streamflow, indicating a strong correlation (Table 4). Simulated higher flow months correlated with observed higher flow months, and simulated lower flow months correlated with observed lower flow months. Therefore, the simulated Dam-Out streamflow systematically shifted the normal streamflow behavior of Grand River when this is dam in.

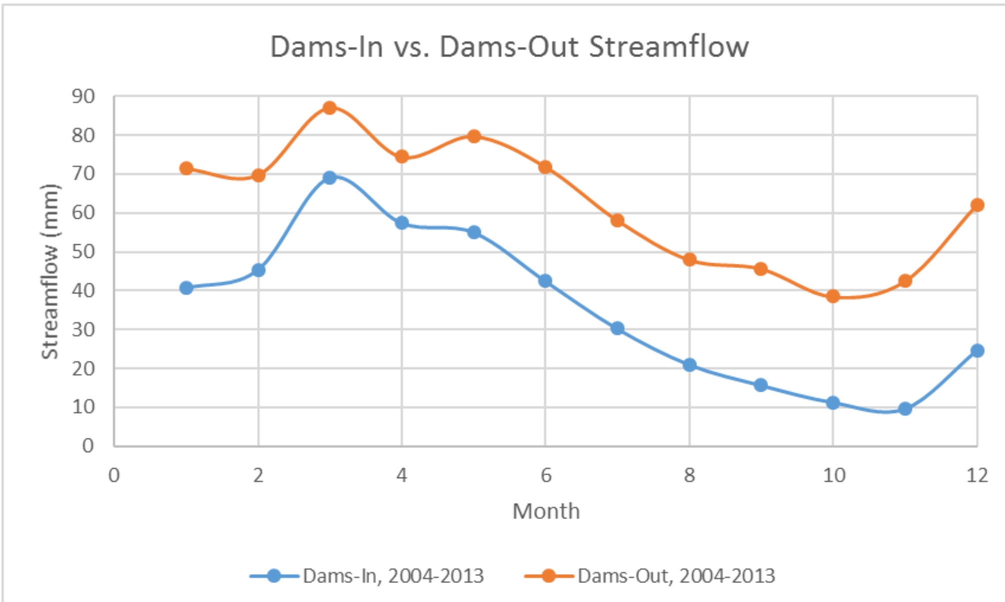

Figure 5. Graph of dams-in and dams-out streamflow outputs.

4 DISCUSSION

4.1 Model Performance

The first purpose of this research was to accurately represent hydrologic conditions in the Grand River Watershed. Statistical analysis of the dams-in scenario confirmed the difficulty in using SWAT to represent conditions in the delineated watershed. Pearson's correlation coefficient signified strong agreement between calibrated/validated data and observed data, and between dams-in data and dams-out data. NSE values were predominantly greater than 0 and were in the acceptable range for general model simulations. However, other error statistics indicated that the model-produced values were not acceptable for representing watershed conditions, based on measures of statistical significance.

SWAT results followed roughly the same pattern of streamflow throughout the year as the observed USGS streamflow. The cause of the overestimations is likely inaccurate representations of infiltration, with which SWAT has been known to have errors (Kleinschmidt 2010). Southern Michigan has little topographic relief, and a DEM with a finer spatial resolution may have better represented the topography and natural flow basins of the watershed. Errors may also be attributed to biases of the NSE and R^2 statistics towards higher flow events (Arnold et al. 2012b), as individual months had more extreme NSE values that skewed the seasonal and annual NSE values.

The second purpose of this research was to determine if a significant difference existed between streamflow in a dams-in scenario and a dams-out scenario. Since the measured dam-out streamflow data is not on record with the USGS, the results of the dams-out modeling were not validated. While the increase in streamflow from a dams-in scenario to a dams-out scenario was substantial, it is not considered statistically significant because of the difference between modeled data and observed data. However, the dams-out scenario is well represented by the model because the whole behavior of the immediate river will have changed.

4.2 Implications of Results

The third purpose of this research was to make recommendations for dam management and flood mitigation in Lansing. With respect to the third purpose of this research, the City of Lansing should still consider flood mitigation and waterfront redevelopment options in association with dam removal and the potential for increased streamflow in the study area. Since city officials have targeted dam removal as their Best Management Practice, we recommend for the drafting of an Environmental Impact Statement to determine the cumulative effects of removing the dams. Definitive recommendations regarding dam removal and flood mitigation strategies would be strengthened with flood frequency analysis and alterations of the river using SWAT or other simulation models (Lee et al., 2017). Overall, the results of the research imply the importance of primary data acquisition for improved hydrologic modeling and the potential hydrologic effects of dam removal scenarios in the Great Lakes region. Future dam removal analysis in this region should expand the research scope to investigate the cumulative effects of dam removal under changing climate, urbanization, and intergovernmental water policy scenarios.

4.3 Study Limitations

Limited stream flow, land use/land cover, and weather data exists from prior to construction of the Moores Park and North Lansing Dams. Thus, calibration and validation of the model was not assessed in a dam-out scenario. Simulation of the dam-out scenario followed the same temporal span as in the dam-in calibration and validation procedure. A considerable obstacle was the lack of available monthly streamflow data for each dam. This limitation was remedied by substituting the maximum discharge at each dam for the target release flow. Other obstacles included estimations of volume to fill the emergency spillway, volume to fill the principal spillway, and surface area when filled to the emergency spillway. Previous work by Murphy (2010) discusses the inaccuracies in modeling reservoirs in SWAT.

Three error scenarios in SWAT hydraulic calibration include the model failing to simulate peak flow events, the model overpredicting surface flow and base flow throughout the year, and the model lagging observed flow despite following the pattern of observed data (Arnold et al. 2012b). The most prevalent errors with this hydraulic calibration were overpredictions of surface flow and base flow amounts. This required manipulating model parameters during sensitivity analysis as previously outlined.

Calibration and validation for streamflow should be process-based and account for hydrologic variables including evapotranspiration, surface runoff, groundwater recharge, lateral flow, and deep aquifer recharge (Arnold et al. 2012b). While several studies have utilized automatic calibration and validation techniques, manual calibration was utilized and intended to work as a function of selected sensitivity parameters, uncertainty ranges, and acceptable R^2 and NSE statistics (Santhi et al. 2001).

To depict the streamflow values for the watershed, we would have needed to adjust hydrologic parameters beyond realistic values for the catchment. Some trial calibrations produced a yearly streamflow amount within 10% of the observed yearly streamflow amount. However, this required adjusting the threshold water depth in the shallow aquifer required for the base flow to occur, to a high value (~1000mm). This parameter increase caused the baseflow index to fall below 5%.

Despite ongoing efforts to adjust hydrologic parameters and calibrate/validate baseline streamflow results, there existed inaccuracies in replicating conditions in the study area. Modeled streamflow was only able to statistically match observed streamflow with extreme adjustment of hydrologic parameters beyond the acceptable values for SWAT. However, from an urban planning perspective, the overestimated model results in both the dams-in and dams-out scenarios are still useful. If Lansing city officials adapted this study in their flood mitigation strategies, model overestimations would highlight the potential of increased streamflow with the dams removed. This potential for increased streamflow may be most significant for peak flow events during late winter or early spring flooding, when greater deviations in streamflow from the long-term average would be expected (Hanshue and Harrington 2011).

5 CONCLUSIONS

This study utilized the Soil and Water Assessment Tool (SWAT) for investigating the effects of removing the Moores Park and North Lansing Dams on streamflow characteristics of the Grand River. The purposes of this research was to model baseline watershed conditions, determine the difference in streamflow between a dams-in and dams-out scenario, and suggest waterfront mitigation and management in the study area. 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.

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.

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