

Impacts of Urban Development on Flooding: A Case Study of Flamingo and Tropicana Watershed, Clark County

Tahir Ali Shaikh¹; Rubab Saher²; Sajjad Ahmad, Ph.D., M.ASCE³;
Daniel Gerrity, Ph.D., M.ASCE⁴; and Haroon Stephen, Ph.D., M.ASCE⁵

¹Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV. Email: shaikt2@unlv.nevada.edu

²Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV. Email: rubab.saher@unlv.edu

³Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV. Email: sajjad.ahmad@unlv.edu

⁴Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV. Email: daniel.gerrity@unlv.edu

⁵Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, Las Vegas, Las Vegas, NV. Email: haroon.stephen@unlv.edu

ABSTRACT

Las Vegas valley has undergone significant development, thus increasing urban flooding. This study analyzes the impacts of urban development on urban flooding in the Flamingo watershed by using a watershed model. The input data includes precipitation, soil characteristics, elevation, and land cover. Urban development is incorporated through increasing percent impervious. Sub-watersheds and streamlines were delineated in ArcGIS using digital elevation model (DEM) dataset. Natural Resources Conservation Service (NRCS) curve-number method was used for the calculation of runoff. The Hydrologic Engineering Center-Hydrologic Management System (HEC-HMS) was used to estimate the discharge hydrograph. The model was calibrated through changing the curve number of the sub-basins. Two urbanization scenarios created with a 5% and 10% increase in impervious surfaces were generated. The results showed that peak discharge occurred earlier due to increase in impervious surfaces. Moreover, the total discharge volume and peak discharge for a given storm event were increasing due to increased imperviousness from urbanization. This study provides useful insight into a hydrological response to urban development that can be helpful in flood remediation.

Keywords: Urbanization; Discharge hydrograph; Runoff modelling; Impervious surface; HEC-HMS; HEC-GeoHMS.

INTRODUCTION

Urban flooding can be caused by high intensity rainfall, long storm duration, rapid snow melt, saturated soils, impervious surfaces and inadequate capacity of storm drains. Climate change can alter snowmelt rate, storm intensity, and storm duration resulting in changes in streamflow and flooding (Kalra et al., 2017; Dawadi and Ahmad 2012; Pathak et al., 2016, 2017; Sagarika et al., 2014, 2015; Saifullah et al., 2019; Siyal et al., 2019 and Tamaddun et al., 2017, 2019). Urbanization by transforming barren lands into developed surfaces can impact perviousness resulting in flooding. In extreme cases this can lead to a natural disaster (Mosquera-Machado and Ahmad 2007). Studies have reported that urban development is one of the most sensitive parameters in the behavior of stream floods. An urbanized watershed generates relatively more

surface runoff as compared to a non-urbanized watershed (Alfy, 2016; Sheng & Wilson, 2009). Consequently, urbanization has a linear relationship with flood volume and peak discharge (Du et al, 2012; Sheng and Wilson, 2009).

Las Vegas Valley (LVV) has undergone major development in the past (Qaiser et al., 2013). This development has been in the form of replacement of barren lands to developed surfaces that include residential, commercial and asphalt areas. These surfaces have changed the surface energy and water budget of the valley (Saher et al, 2019). Consequently, the development of various surfaces has induced an increase in runoff, and shortening of time of concentration, creating a threat of urban floodings.

Studies have determined the impacts of urbanization on surface runoff using hydrograph simulation with different models (Ahmad et al., 2009, 2010; Zhang et al., 2016; Ahmad and Simonovic 2005). HEC-HMS has reportedly been an effective tool to understand the response of rainfall-runoff on the surfaces (Forsee & Ahmad, 2011; Nyaupane et al, 2018; Thakali et al., 2016). The effects are analyzed on the watershed by simulating the surface and sub-surface hydrologic conditions (Chen et al., 2019). These conditions involve the soil characteristics, percentage of imperviousness, lag time, drainage flow paths, slope and drainage area of the watershed. Rind et al (2018) used HEC-HMS tool to determine the drainage characteristics. Beighley et al (2003) simulated rainfall runoff responses in Mediterranean climate using HEC-HMS model. Chu and Steinman (2009) employed HEC-HMS to investigate the responses of a basin to an individual storm event. Gumindoga et al (2017) applied HEC-HMS to simulate runoff from 2004 through 2010 in upper Manyame sub-catchment. Oleyiblo and Li (2010) investigated the applicability and capability of the HEC-HMS and HEC-GeoHMS models for flood forecasting and reported determination coefficient (R^2) as 0.9.

This study examines the effects of urbanization on peak discharge, time, and total runoff volume. The main objectives of the study are to develop a model for determining peak discharge and runoff volume, and to determine the impacts of increased imperviousness on the discharge hydrograph.

STUDY AREA AND DATA DESCRIPTION

Study Area

The Flamingo watershed, Clark County, Nevada was selected as the study area (Figure 1). The watershed covers an area of 587.8 km² and extends from west to the center of the Clark County, Las Vegas Valley. The selected watershed encompasses four major land covers including residential, commercial, road infrastructures, and barren surface. The valley has an arid climate with long hot summers with an average high temperature of 94.5°F, and mild to chilly winters with an average low temperature of 73 °F (U.S. Climate Data, 2019). The valley receives an average annual rainfall of approximately 11.45 cm (CCRFCD, 2006).

Data Acquisition

The digital elevation model (DEM) was retrieved from the Shuttle Radar Topography Mission (SRTM), with a spatial resolution of DEM is 30 m. Soil data were retrieved using Environmental Protection Agency (EPA) Stormwater Calculator. Land cover datasets were retrieved from North American Land Data Assimilation System (NLDAS). Both rainfall and discharge data were retrieved from the United States Geological Survey (USGS) station # 094196781. The temporal resolution of both datasets is 5 minutes.

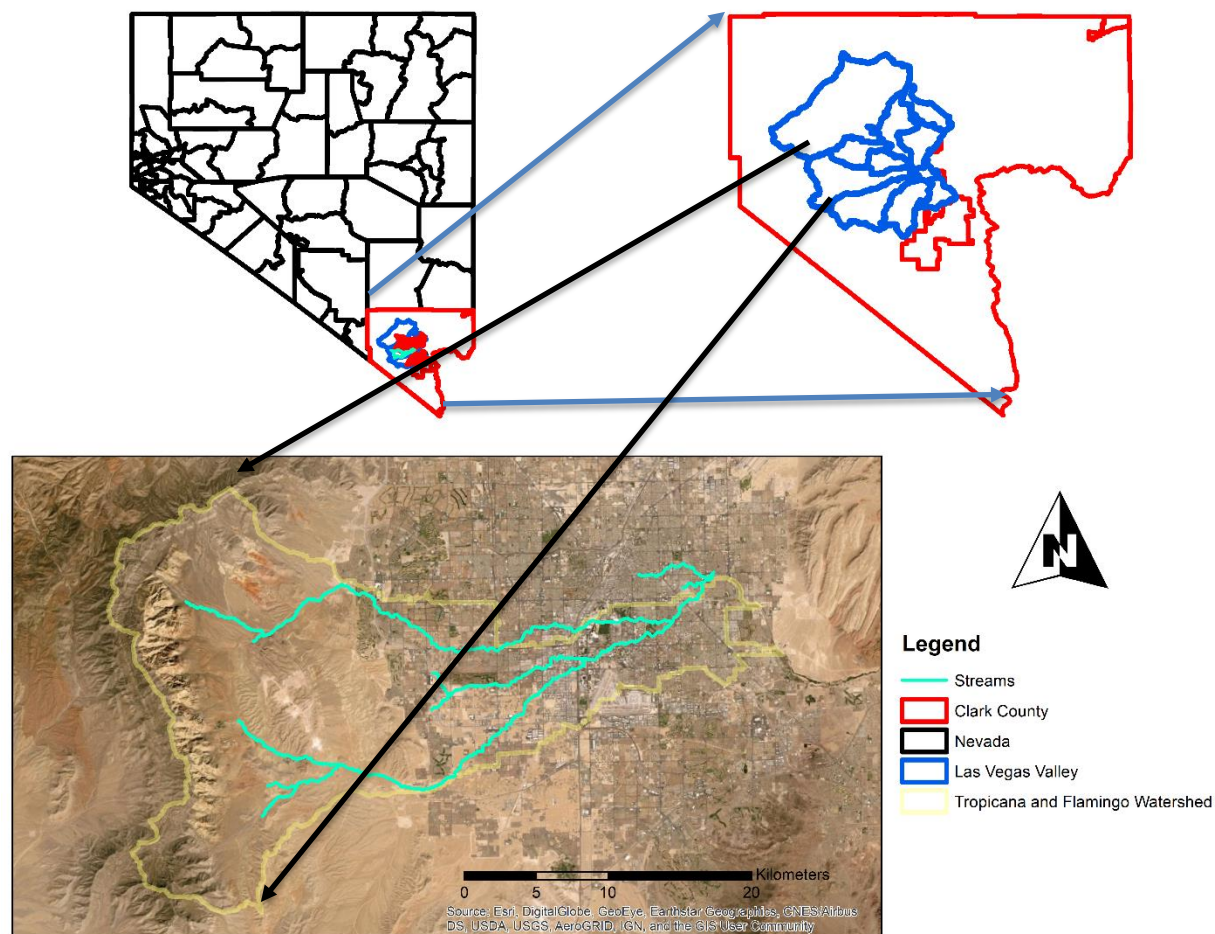


Figure 1. Map of the study area showing the location of Flamingo and Tropicana watersheds in Clark County (above) and watershed boundary (below).

Methodology

This section provides an overview of the steps followed for the study. Overall, the methodology consists of five steps including (i) delineating sub-watersheds boundaries and streams in Arc-GIS (ii) inputting physical parameters into HEC-HMS to generate hydrograph (iii) calibrating and validating the model (iv) running the model for proposed scenarios. An overall approach is shown in Figure 2.

Watershed Delineation

DEM data is used as the input data for delineation. Major steps of watershed delineation include DEM conditioning; extracting flow direction, flow accumulation, defining stream depth, delineating stream network based on outlet location and finally creating sub-watersheds. These steps extract the physical characteristics of the watershed, including watershed boundaries, area of sub-watersheds, flow paths, sub-watershed slope, and stream slopes.

Hydrologic Modeling in HEC-HMS

The delineated watershed was processed using HEC-GeoHMS to assign sub-basins, reach, junctions, and outlet with their physical characteristics. These characteristics include the area of each sub-basin along with slope, streams and flow lengths. The delineated model is then exported to HEC-HMS for rainfall runoff analysis.

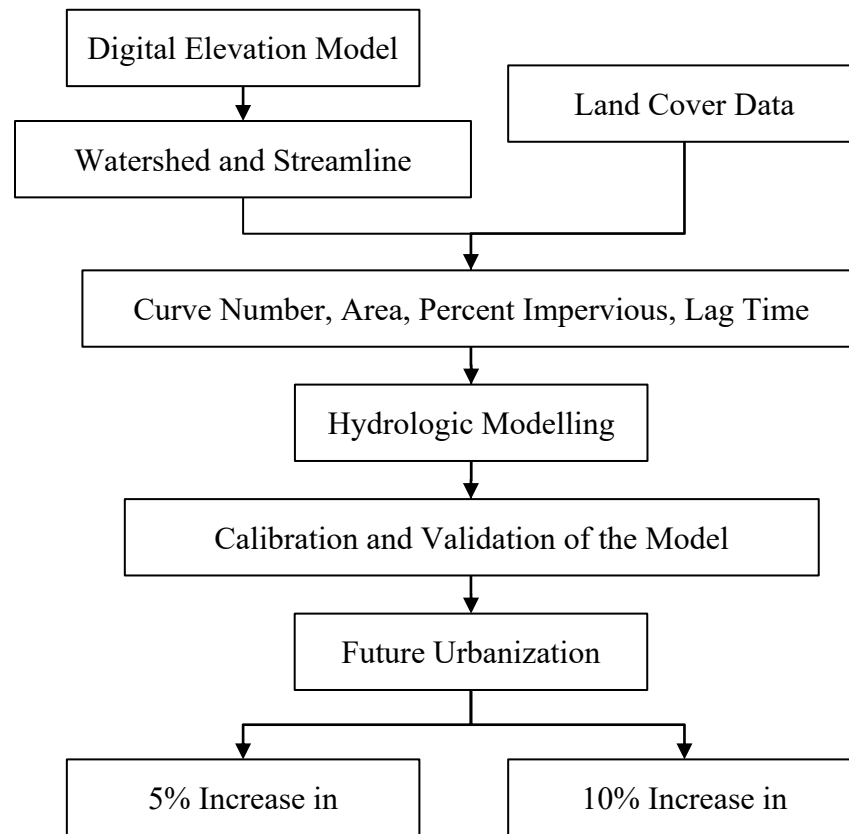


Figure 2. Flowchart of the methodology for determining impacts of increased urbanization on discharge hydrograph.

For the rainfall runoff analysis, simulation of real time surface drainage conditions is crucial. This is done by estimating the lag time, curve number, and percentage impervious of each sub-basin. Curve number is a function of land use and soil type. The properties of soil were retrieved from EPA stormwater calculator. Three major types of soil groups have been reported in the Flamingo watershed (A, B and D). There are two approaches to estimate losses within a sub-basin. The first approach involves using area-weighted curve number and the second approach involves area-weighted discharge. Former approach was used in this study. The NRCS curve number method was used to generate runoff from rainfall. The method is designed for a single storm event. Curve number can be determined using soil type and land cover data. Curve number for each land use class was determined using guidelines provided by National Resources Conservation Service (NRCS) guidelines. Weighted curve numbers for each watershed was determined using the equation

$$CN_{composite} = \sum \frac{A_i \times CN_i}{A_i}$$

where $i = 1, 2, \dots, 20$, A is the area covered by land use type, and CN is the curve number of the area. Lag time is the function of overland flow length and has been determined using the equation (NRCS, 2004)

$$T_{lag} = L^{0.8} \frac{(S + 1)^{0.7}}{1900\sqrt{Y}} * 60$$

where T_{lag} is lag time in minutes, L is the maximum length of stream in feet, Y is watershed slope and S is the maximum retention in a watershed in inches. Maximum retention of a watershed (S) can be determined using the equation (NRCS, 1986)

$$S = \frac{1000}{CN} - 10$$

where S is the maximum retention in a watershed in inches and CN is the curve number of sub-watersheds.

The initial input values of weighted curve numbers, maximum surface retention, and lag time of each sub-basin are summarized in Table 1.

Model Calibration and Validation

Once the drainage characteristics of sub-basins were estimated, the model was calibrated using a two-day storm event (09 May 2019 through 11 May 2019, 17.3 mm of precipitation). The volume, peak discharge, and time of peak values of generated hydrograph and observed hydrograph were compared. The discrepancies in both hydrographs were addressed by changing the curve number.

Table 1. Initial calculated input parameters of the model.

Sub basin	Area (km ²)	Curve Number	Initial Abstraction (mm)	Lag Time (minutes)
W180	38.7	91	5.1	50
W190	0.4	91	4.8	4
W210	30.1	91	5.1	36
W220	4	76	16.3	18
W240	88.8	83	10.4	38
W250	11.5	78	14.7	24
W260	90.4	78	14.2	23
W270	30.1	80	12.7	34
W280	67.6	83	10.2	46
W300	78.3	81	11.7	26
W310	77.2	79	13.5	29
W340	70.7	78	14.5	25

Validation of the model was done using two days stream gage discharge data from Sep 8, 2017 through Sep 10, 2017. In response to a precipitation event of 7.1 mm. The measure of error was the deviation of simulated discharge values from the observed data available at 5 min interval. The performance of the model was evaluated using the Nash-Sutcliffe efficiency coefficient (NSE). The coefficient range between $-\infty$ and 1; an NSE of 1 typically means that the model corresponds well to observed values. In literature the values of NSE for a reasonable model range between 0.5 and 0.65.

Running Model for Proposed Scenarios

Urbanization impacts were assessed by devising two scenarios with 5% and 10% increase in the urbanized area with respect to the base scenario. These scenarios were simulated for the base rainfall event. The assessment of urbanization of runoff has been quantified by analyzing the changes in runoff volume, peak discharge, and peak discharge time at the outlet.

RESULTS AND DISCUSSION

Watershed Delineation

Delineation generated twelve sub-basin, eight junctions, eight reaches and an outlet at the downstream of the watershed as shown in Figure 3. Area of the sub-basins is the primary parameter for setting-up a basin model. Areas of each sub-basin obtained from the process are summarized in Table 2. Sub-basins W240 and W260 covered the largest areas 90.5 km^2 and 88.8 km^2 , respectively. The upstream area of the watershed is covered by barren mountains and barren lands. The central area of the watershed covers barren lands and light developed to highly developed areas. Downstream area of the watershed is covered by moderately developed to highly developed area. Sub-basins W260, W310 and W340 are on the upstream of the watershed. W190 is at the downstream of the watershed and contributes directly to the outlet.

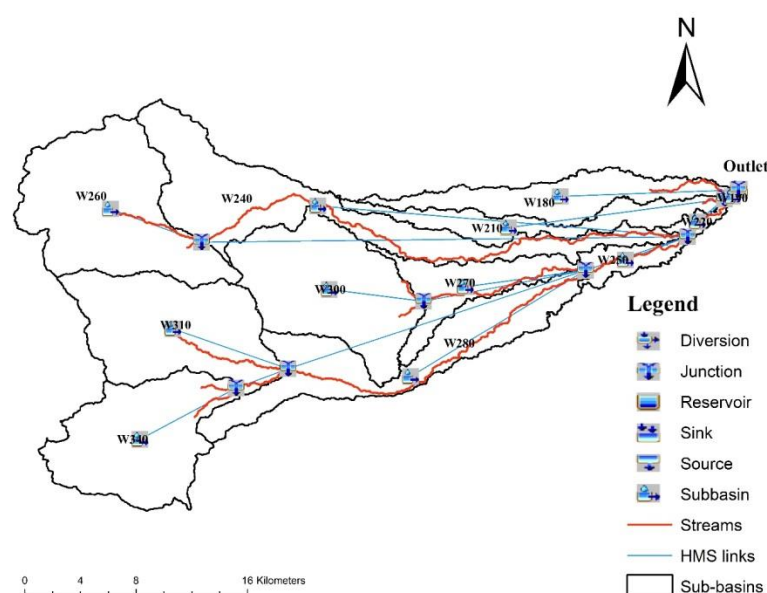


Figure 3. Map of the delineated watershed showing all the elements of the watershed.

Hydrologic Modelling Using HEC-HMS

The runoff simulation was done by using the estimated weighted curve numbers and lag times of each sub-basin. The non-calibrated hydrograph at the outlet is presented in Figure 4. The simulated peak discharge 17.5 m³/sec, occurred on 10 May 2019, 03:05, whereas, observed peak discharge of 19.5 m³/sec occurred on 10 May 2019, 00:40. The model performed well with NSE of 0.65 on event of 2 hours and 25 minutes earlier than that simulated. The two-day rainfall event generated 0.76 mm of runoff and observed runoff was 0.74 mm. The percentage bias was 2.52%.

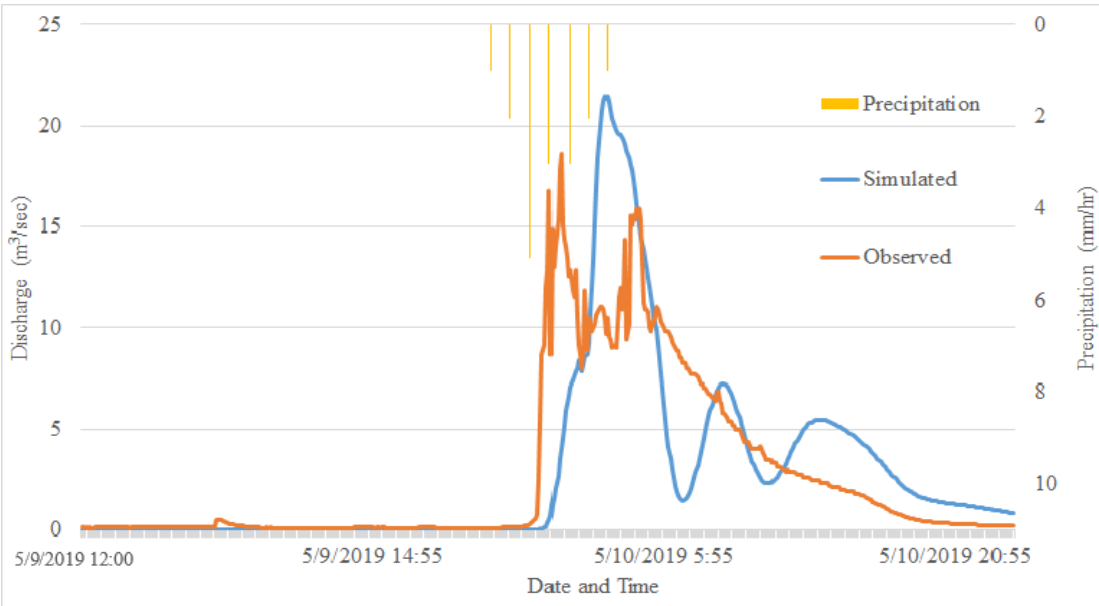


Figure 4. Two-day discharge hydrograph at the outlet before model calibration.

Model Calibration and Validation

The main objectives of the calibration were decreasing the percent error of volume generated at the outlet, decreasing lag time, and matching the peak discharge. Calibrated curve numbers are summarized in Table 2.

During model calibration, lag time was reduced and calibrated with observed lag time. Total error in discharge volume accumulated at the outlet decreased from positive 2.52% to negative 1.64%, whereas calibrating the peak discharge at the outlet was 0.85m³/sec higher than observed (Figure 5). It was observed that the model is extremely sensitive to sub-basin W180 because of its curve number, area and location, or spatial distribution of precipitation.

The model did not perform well during the validation. Simulated runoff at the outlet for the storm event was 0.03 mm compared with 0.18 mm of observed runoff at the gauge, this resulted in a RMSE of 1.2 (Figure 6).

Proposed Scenarios

Results show that the sub-basin with greater curve number have lesser impact of increase in curve number. Due to the increase in imperviousness, the rainfall transforms into discharge earlier and generates more volume, which causes an increased volume at the outlet and an earlier and greater peak discharge at the outlet. The increase in imperviousness has a linear relationship

with volume generated at the outlet (Figure 7). The results obtained from the model run are summarized in Table 3.

Table 2. Curve numbers of all sub-basins before calibration and after calibration.

Sub-basin	Initial Curve Number	Calibrated Curve Number
W180	91	92
W190	91	91
W210	91	91
W220	76	76
W240	83	83
W250	77	76
W260	78	75
W270	80	78
W280	83	80
W300	81	81
W310	79	79
W340	78	78

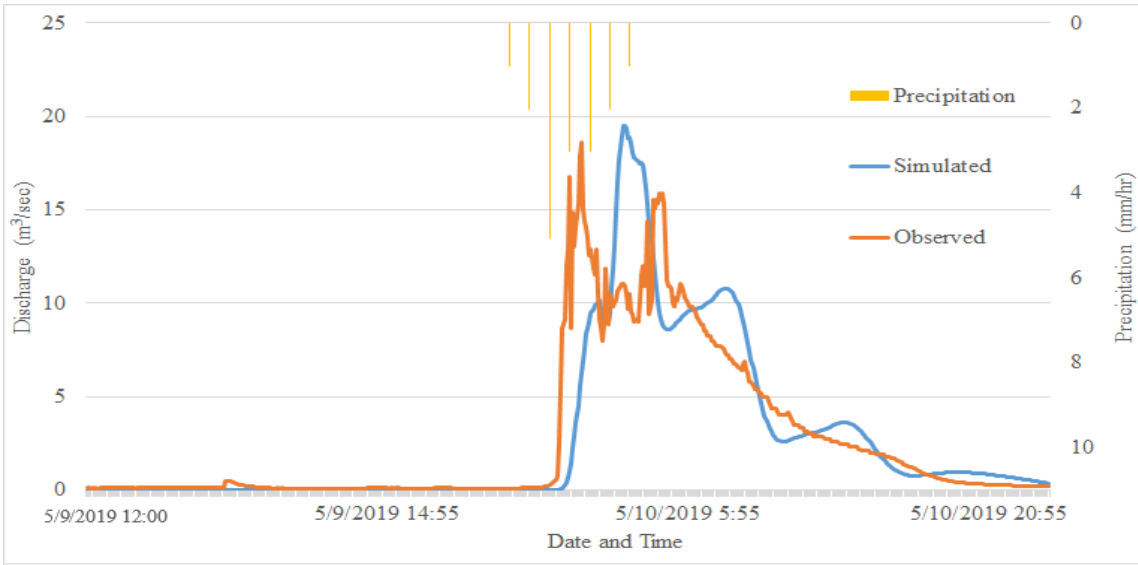


Figure 5. Simulated two-day discharge hydrograph at the outlet after model calibration.

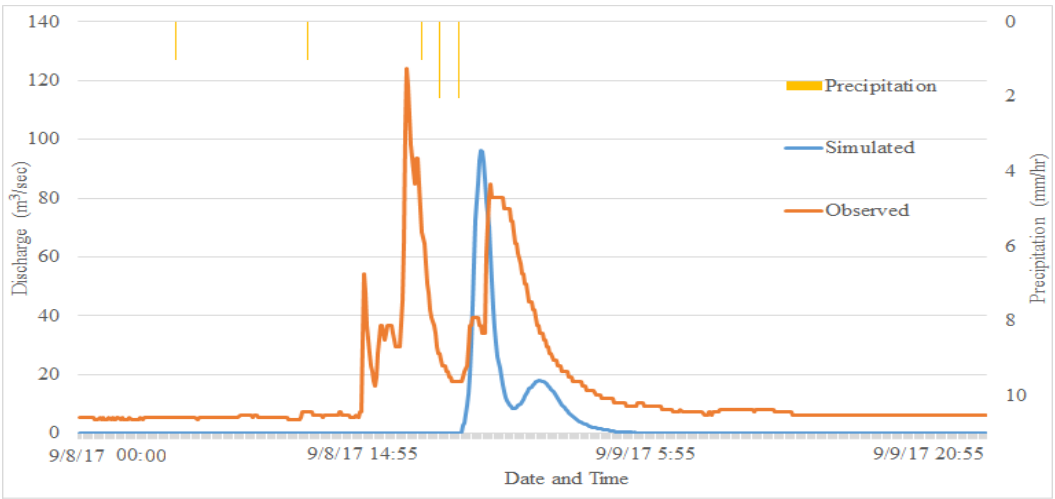


Figure 6. Simulated two-day discharge hydrograph at the outlet for validation.

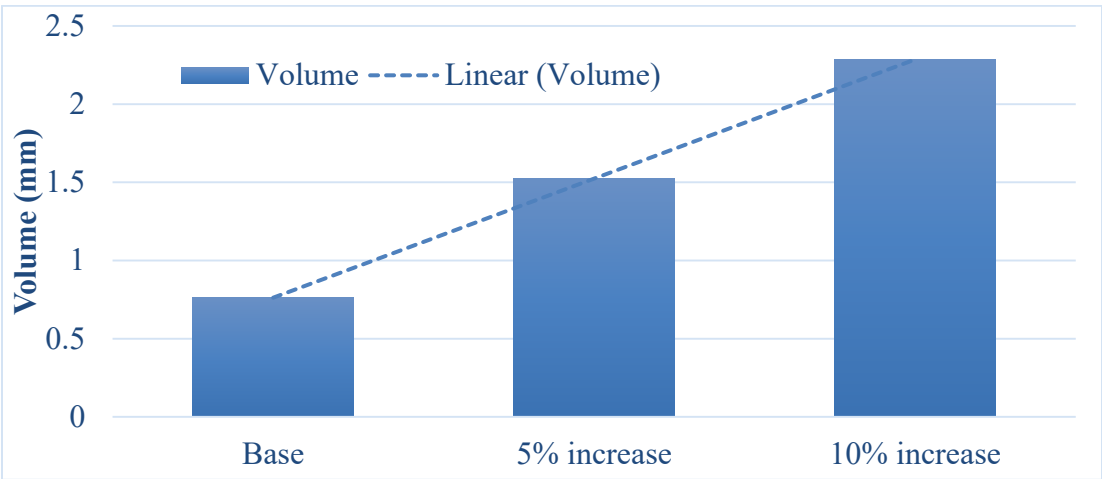


Figure 7. Increase in volume with increase in percent impervious and linear relationship between percent impervious and discharge volume at the outlet

CONCLUSION

The objective of this study was to determine the effects of urbanization on the discharge hydrograph. The analysis was conducted using soil data, and remote sensing datasets including DEM and land cover of the area. The runoff model HEC-HMS was calibrated using two-day events and validated. To understand the effects of urbanization on discharge hydrograph, two scenarios were created based on increase in percentage imperviousness. The findings suggest that percent impervious has a linear relationship with the total volume generated from the watershed. Lesser impact on the sub-watersheds having larger curve numbers was observed. It was noted that the peak discharge increases and occurs earlier with increasing urbanization. This study is important to understand the impacts of urbanization on discharge volume generated at the outlet and to understand the responses of imperviousness on peak volume and time.

Table 3. Volume generated from each sub-basin for base scenario and 5% and 10% increase in imperviousness.

Sub-basin	Volume before urbanization (mm)	Volume after 5% increase in imperviousness (mm)	Volume after 10% increase in imperviousness (mm)
W180	4.7	5.4	6
W190	4.6	5.6	6.2
W210	4	4.6	5.3
W220	0	0.6	1.7
W240	0.8	1.6	2.4
W250	0	0.9	1.7
W260	0	0.9	1.7
W270	0.1	1	1.8
W280	0.3	1.2	2
W300	0.4	1.3	2.1
W310	0.2	1	1.9
W340	0.1	1	1.8

It is crucial to further calibrate the model through incorporating additional parameters, changing the routing method, and changing the optimization method. The model didn't perform well during validation and percent bias were greater than acceptable limits. The reason for this may be the use of only one precipitation gauge for entire watershed. Nevertheless, the study provides a better understanding of increase in urbanization on sub-basin and watershed hydrology.

REFERENCES

- Ahmad, M.M., Ghumman, A.R., and Ahmad, S. (2009). Estimation of Clark's instantaneous unit hydrograph parameters and development of direct surface runoff hydrograph. *Water resources management*, 23(12), 2417-2435.
- Ahmad, M.M., Ghumman, A.R., Ahmad, S., and Hashmi, H.N. (2009) Estimation of a Unique Pair of Nash Model Parameters: An Optimization Approach, *Water Resources Management* 24(12) 2971-2989.
- Ahmad, S., and Simonovic, S.P. (2005), An Artificial Neural Network model for generating hydrograph from hydro-meteorological parameters, *Journal of Hydrology*, 315 (1-4), 236-251.

- Beighley, R.E., Melack, J.M., and Dunne, T. (2003). Impacts of California's climatic regimes and coastal land use change on streamflow characteristics 1. *JAWRA Journal of the American Water Resources Association*, 39(6), 1419-1433.
- Chen, C., Kalra, A., and Ahmad, S. (2019). Hydrologic responses to climate change using downscaled GCM data on a watershed scale. *Journal of Water and Climate Change*, 10(1), 63-77.
- Chu, X., and Steinman, A. (2009). Event and continuous hydrologic modeling with HEC-HMS. *Journal of Irrigation and Drainage Engineering*, 135(1), 119-124.
- Dawadi, S., and Ahmad, S. (2012). "Changing climatic conditions in the Colorado River Basin: Implications for water resources management." *J. Hydrol.*, 430-431, 127-141.
- Du, J., Qian, L., Rui, H., Zuo, T., Zheng, D., Xu, Y., and Xu, C. Y. (2012). Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhua River basin, China. *Journal of Hydrology*, 464, 127-139.
- El Alfy, M. (2016). Assessing the impact of arid area urbanization on flash floods using GIS, remote sensing, and HEC-HMS rainfall-runoff modeling. *Hydrology Research*, 47(6), 1142-1160.
- Forsee, W.J., and Ahmad, S. (2011). Evaluating urban storm-water infrastructure design in response to projected climate change. *Journal of Hydrologic Engineering*, 16(11), 865-873.
- Gumindoga, W., Rwasoka, D.T., Nhapi, I., and Dube, T. (2017). Ungauged runoff simulation in Upper Manyame Catchment, Zimbabwe: Application of the HEC-HMS model. *Physics and Chemistry of the Earth, Parts A/B/C*, 100, 371-382.
- Kalra, A., Sagarika, S., Pathak, P., and Ahmad, S. (2017) Hydro-climatological changes in the Colorado River Basin over a century, *Hydrological Sciences Journal* 10.1080/02626667.2017.1372855
- Mosquera-Machado, S., and Ahmad, S. (2007). Flood hazard assessment of Atrato river in Colombia, *Water Resources Management*. 21(3): 591-609.
- NRCS, USDA. (1986). Urban Hydrology for Small Watersheds TR-55. USDA Natural Resource Conservation Service Conservation Engineering Division, *Technical Release*, 55, 164.
- NRCS, USDA. (2004). Estimation of direct runoff from storm rainfall. *National Engineering Handbook* Part, 630.
- Nyaupane, N., Mote, S. R., Bhandari, M., Kalra, A., and Ahmad, S. (2018). Rainfall-Runoff Simulation Using Climate Change based Precipitation Prediction in HEC-HMS Model for Irwin Creek, Charlotte, North Carolina. In *World Environmental and Water Resources Congress*, Minneapolis, MN pp. 352-363.
- Oleyiblo, J. O., and Li, Z. J. (2010). Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China. *Water Science and Engineering*, 3(1), 14-22.
- Pathak, P., Kalra, A., and Ahmad, S. (2016) Temperature and Precipitation changes in the Midwestern United States: Implications for water management, *International Journal of Water Resources Development*, 10.1080/07900627.2016.1238343.
- Pathak, P., Kalra, A., Lamb, K.W., Miller, W.P., Ahmad, S., Amerineni, R., and Ponugoti, D.P. (2017) Climatic variability of the Pacific and Atlantic Oceans and western U.S. snowpack, *International Journal of Climatology*.
- Qaiser, K., Ahmad, S., Johnson, W., and Batista, J.R. (2013). "Evaluating water conservation and reuse policies using a dynamic water balance model." *Environ. Manage.*, 51(2), 449-458.

- Rind, M.A., Ansari, K., Saher, R., Shakya, S., and Ahmad, S. (2018). 2D Hydrodynamic Model for Flood Vulnerability Assessment of Lower Indus River Basin, Pakistan. In World Environmental and Water Resources Congress, Minneapolis, MN.
- Sagarika, S., Kalra, A., and Ahmad, S. (2014). "Evaluating the effect of persistence on long-term trends and analyzing step changes in streamflows of the continental United States." *Journal of Hydrology*, 517, 36–53.
- Sagarika, S., Kalra, A., Ahmad, S. (2015). "Interconnection between oceanic-atmospheric indices and variability in the US streamflow." *Journal of Hydrology*, 525, 724-736.
- Saher, R., Ahmad, S., and Stephen, H. (2019). Analysis of Changes in Surface Energy Fluxes Due to Urbanization in Las Vegas. In World Environmental and Water Resources Congress, Pittsburgh, PA.
- Saifullah, M., Liu, S., Tahir, A. A., Zaman, M., Ahmad, S., Adnan, M., and Mehmood, A. (2019). Development of Threshold Levels and a Climate-Sensitivity Model of the Hydrological Regime of the High-Altitude Catchment of the Western Himalayas, Pakistan. *Water*, 11(7), 1454.
- Sheng, J., and Wilson, J. P. (2009). Watershed urbanization and changing flood behavior across the Los Angeles metropolitan region. *Natural Hazards*, 48(1), 41-57.
- Siyal, A.A., Bhatti, A.M., Babar, M.M., Ansari, K., Saher, R., and Ahmad, S. (2019). Environmental Impact of Conversion of Natural Wetland into Reservoir: A Case Study of Chotiari Reservoir in Pakistan. In World Environmental and Water Resources Congress, Pittsburgh, PA.
- Suriya, S., and Mudgal, B.V. (2012). Impact of urbanization on flooding: The Thirusoolam sub watershed—A case study. *Journal of hydrology*, 412, 210-219.
- Tamaddun, K., Kalra, A., Kumar, S., and Ahmad, S., (2019) CMIP5 Models' Ability to Capture Observed Trends under the Influence of Shifts and Persistence: An In-depth Study on the Colorado River Basin. *Journal of Applied Meteorology and Climatology*, <https://doi.org/10.1175/JAMC-D-18-0251.1>.
- Tamaddun, K., Kalra, A., Bernardez, M., and Ahmad, S. (2017) Multi-scale Correlation between Western U.S. Snow Water Equivalent and ENSO/PDO Using Wavelet Analyses, *Water Resources Management* 10.1007/s11269-017-1659-9.
- Thakali, R., Kalra, A., and Ahmad, S. (2016) Understanding the Effects of Climate Change on Urban Stormwater Infrastructures in the Las Vegas Valley, *Hydrology*, 3(4), 34.
- Thakur, B., Kalra, A., Ahmad, S., Lamb, K. W., and Lakshmi, V. (2020). Bringing statistical learning machines together for hydro-climatological predictions-Case study for Sacramento San joaquin River Basin, California. *Journal of Hydrology: Regional Studies*, 27.
- U.S. Climate Data. (2020, 02 15). usclimatedata. From climate/las-vegas: www.usclimatedata.com
- Zhang, F., Ahmad, S., Zhang, H., Zhao, X., Feng, X., and Li, L (2016). "Simulating low and high streamflow driven by snowmelt in an insufficiently gauged alpine basin." *Stochastic Environmental Research and Risk Assessment*, 30: 59-75.