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Ranjeet Thakali
Southern Illinois University, ranjeet@siu.edu

Ranjit Bhandari
Southern Illinois University

Giles-Arnaud Arif-Deen Kandissounon
Southern Illinois University

Ajay Kalra
Southern Illinois University, kalraa@siu.edu

Sajjad Ahmad
University of Nevada, Las Vegas, sajjad.ahmad@unlv.edu

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Flood Risk Assessment Using the Updated FEMA Floodplain Standard in the Ellicott City, Maryland, United States

Ranjeet Thakali[1]; Ranjit Bhandari[1]; Gilles-Arnaud Arif-Deen Kandissounon[1]; Ajay Kalra[1]; and Sajjad Ahmad[2]

[1]Dept. of Civil and Environmental Engineering, Southern Illinois Univ., 1230 Lincoln Dr., Carbondale, IL 62901-6603. E-mail: ranjeet@siu.edu

[2]Dept. of Civil and Environmental Engineering and Construction, Univ. of Nevada, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4015.

Every Year, flooding causes a calamitous impact on the people, economy, and environment all over the world. In recent years, the flood-related damages have been increasing in the United States regardless of several investments in the flood control measures. Floodplain mapping is an important tool for management that aids in the planning of infrastructures within the floodplain zone. With the magnifying effects of climate change on the hydrological cycle the study of floodplain is becoming a key tool in the water management. Federal Emergency Management Agency has recently updated their floodplain standard as per the presidential executive order 2015 on the Federal Flood Risk Management Standard. This study incorporates the newly updated floodplain mapping standard in the flood risk assessment of approximately 11.2 km stretch of the Patapsco River near Ellicott City. Hydrologic Engineering Center's River Analysis System (HEC-RAS) with the conjunction of geographical information systems were used in the floodplain analysis. The different return period flows (2, 5, 10, 25, 50, 100, and 500) were used from the frequency analysis. These flows were routed through the selected reach of Patapsco River and the vulnerability assessment of the nearby existing infrastructures was conducted. This study can assist the decision makers and planner for the implementation of flood protection measures near the Ellicott City.

Introduction:

Hurricanes storms are the leading causes of flooding in the United States. According to the United States Geological Survey (USGS), flooding is responsible for over 75% of natural disasters in the country (USGS, 2012). Present global temperature is rising and climate models have predicted an increasing trend throughout the 21st century (Kalra et al., 2013 a,b; Pachauri et al., 2014; Pathak et al., 2016a,b; Sagarika et al., 2014). In warmed climate, the frequency, intensity, and the severity of extreme climatic events are expected to magnify (Christensen et al., 2007; Paz et al., 2013; Dhakal and Chevalier, 2015; Ghimire et al., 2016; Tamaddun et al., 2016 a,b). Climate change is attributing to the increase in the severe hydrological events such as flooding (Easterling et al., 2000; Kalra and Ahmad, 2011, 2012; Carrier et al., 2013, 2016; Sagarika et al., 2015a,b; Dhakal and Chevalier, 2016). The study of a floodplain aids in the planning and implementation of mitigation techniques in the flood vulnerable area.

A large number of buildings across the United States are located within the boundaries of a floodplain and exposed to major losses and damages should one ever occur. For years, the government have been anticipating flood disasters by constructing flood-control works such as dams and seawalls and providing relief to victims. However, ineffective building techniques combined with rising costs of flood insurance coverage lead Congress to adopt the National Flood Insurance Program (NFIP), in an effort to control flood damages and protect property owners from financial losses (King, 2005). The NFIP is administered by the Federal Emergency Management

Agency (FEMA), which determines the flood prone areas nearby the water bodies that would be submerged due to flooding. Accepting the fact of changing climate FEMA has updated the floodplain standard as per the presidential executive order, COE, 2015.

Delineation of a floodplain zone of a river is essential for proper planning and management of surrounding areas (Mosquera-Machado and Ahmad 2007; Maheshwari et al., 2014). Numerical modeling is a typical method of inundation mapping that demands a tiresome amount of time. A coupled hydraulic model and geographic information systems has been developed and widely used over the course of the past few years to understand the timing and magnitude of floods. The technology integrates Geographical Information Systems (GIS) and hydrologic/hydraulic modeling systems, which can then be used to display the extent of the flood (Colby et al., 2000).

For the past few decades, the Hydraulic Engineering Center's HEC-2 model has been used widely in floodplain mapping (USACE, 1991). It was the first straightforward and automated model, which allowed users to compute surface profiles within a reasonable time frame. The U.S. army Corps of Engineers developed a windows compatible version of HEC-2 model in 1995, for river analysis system (HEC-RAS), (USACE, 1991). The latest versions of HEC-RAS were extended to unsteady flow analyses, which is a remarkable improvement in hydraulic analysis of river systems. HEC-RAS was a significant improvement from the original DOS-based HEC-2 overall, however, neither models offered the possibility to map the water surface elevation (WSE) in the terrain of the study region with in the same model. The recent advancement of HEC-GeoRAS allows the HEC-RAS simulated WSE to overlay with the topographic data in GIS data frame. The primary objective of this study was to delineate floodplain zones of a river system using HEC-RAS-established WSE in GIS. It also provides a good case in examining the suitability of HEC-RAS for flood modeling by performing a case study in the Patapsco River near Ellicott City, Maryland.

Study area and data

Ellicott City lies in the Howard county of Maryland, United States at 39°16′5″N latitude and 76°47′56″W longitude geographic coordinate. This city is a part of the Baltimore-Washington Metropolitan Area. As of U.S. Decennial Census of 2010, the total population in the city was 65,834. The town had witnessed several flooding in the past decades and considered to be an area prone to flooding from the nearby Patapsco River and Tiber Creek (Halverson, 2016). Tiber Creek is one of the tributaries of the Patapsco River. On July 30, 2016, an unprecedented rainfall event resulted in severe flooding that inundated the whole city taking human lives (Rector 2016; Halverson, 2016). That storm poured six inches of rain in the interval of 2 hours. This event was well archived in the newspapers and many online publications. The flood resulting from the Hurricane Agnes on June 22, 1972 was considered the most severe in the flooding history of Ellicott City (Gupta and Fox, 1974). This study used the 11.2 km stretch of the Patapsco River for the flood inundation mapping resulting from flows of different return period and the flow from the 1972 and 2016 flooding events. This stretch of Patapsco River is accompanied by a USGS stream flow gaging station, USGS 01589000. No major hydraulic structures are constructed within this stretch of the Patapsco River.

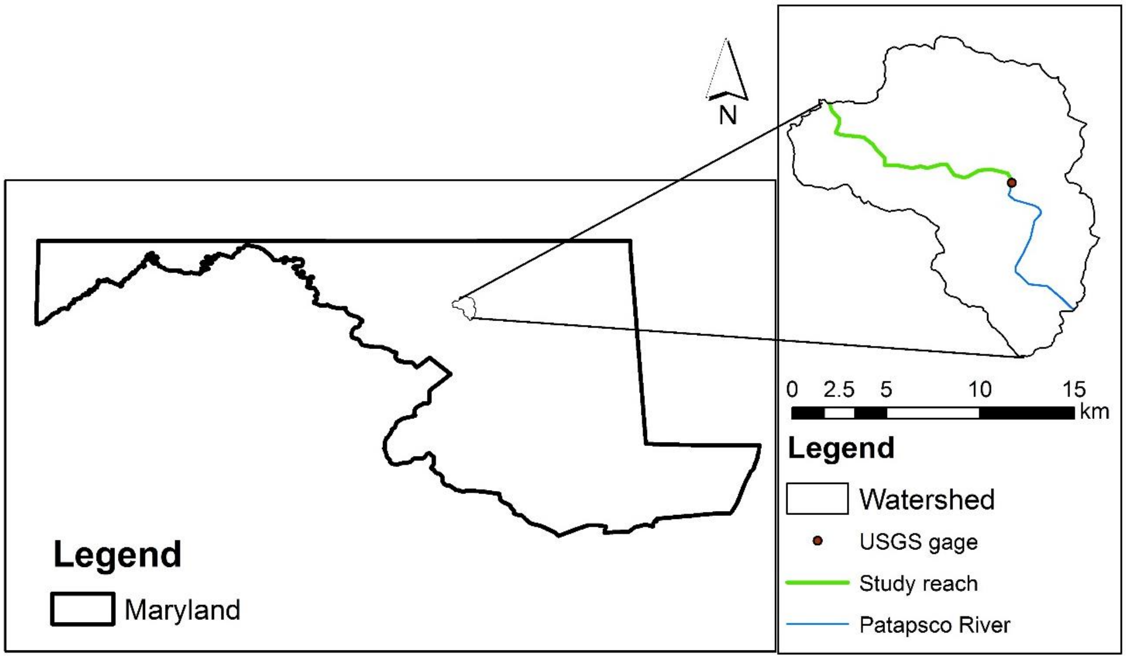

Figure 1: Map showing the study area along with Maryland State of the United States

This study primarily used the terrain data from the 1/9 arc second digital elevation model from the USGS's national map viewer website and the stream flow data from USGS 01589000 (Patapsco River at Hollofield, MD) gage station. These data are openly accessible and the Table 1 shows the corresponding sources of the data.

Table 1: Input data and corresponding source

Data Type	Source
Digital Elevation Model (DEM)- 1/9 arc second	https://viewer.nationalmap.gov/basic/ (National map viewer – USGS)
Stream flow data (discharge and gage height)	http://waterdata.usgs.gov/nwis (USGS)

Method

The methods followed in this study include the analysis using ArcGIS and HEC-RAS for the floodplain mapping and the Generalized Extreme Value (GEV) methods for the calculation of flood frequency. The Geographic Information Systems offers unique graphical user interface and database management tools and can be used to link hydraulic data to spatial location. Physical element descriptions such as cross section parameters can be transferred to GIS using GIS-based tools. At First, Digital Elevation Model (DEM) data obtained from USGS was used for the generation of Triangulated Irregular Network (TIN) data in Arc GIS using the Raster to TIN 3D Analyst tool. The TIN format was then utilized by the HEC-GeoRAS (Ackerman et al., 2000), an extension of ArcGIS, to export the necessary river geometry of the selected stretch of the Patapsco

River to the HEC-RAS. The output of HEC-GeoRAS, which comes in GIS format was imported to the HEC-RAS through the Geometric Data Editor. Initially, the values of manning's roughness coefficient as recommended by Arcement et al., (1989) were fed to the HEC-RAS in the left bank, center, and right bank of each cross-section. The HEC-RAS model was then calibrated and validated with the measured discharges corresponding water surface level by successively changing the initial values of manning's coefficient.

GEV distribution (Hosking et al., 1997) was implemented for the calculation of flows corresponding to the return period of 2, 5, 10, 25, 50, 100 and 500 years. The annual maximum peak discharge from the USGS gage 01589000 was fitted in the GEV distribution and the three parameters, shape, location, and scale of the GEV was calculated using the L-moment. These calculated flows along with two historical peak discharges were then routed in the HEC-RAS model. For all the flows, the water surface profiles were computed considering steady and uniform flow condition. The water surface profile data for each case was exported to HEC-GeoRAS. The water surface in the TIN format for each event was created by HEC GeoRAS and rasterized to compare with the raster DEM for computation of the variation in elevation. The areas where the water surface elevation exceeded the elevation of the terrain defined the floodplain.

Results and Discussion

This section discusses the flood frequency analysis results using GEV followed by the HEC-GeoRAS analysis and the HEC RAS simulation results, and finally the ArcGIS analysis for the inundation mapping.

Flood frequency analysis:

This study used the GEV flood frequency method for the calculation of flows correspoding to different return periods. The return period includes the 500 year which is recently updated in the FEMA standard after presidential executive order 2015 on the Federal Flood Risk Management Standard. Table 2 shows the statistical analysis results for the 2, 5, 10, 25, 50, 100, and 500 year return period predicted discharges. The measured discharge of the July 30, 2016 flooding was 639.96 m^3/s. The maximum recorded discharge in the gage station was 2282.33 m^3/s which was measured on June 22, 1972, a flooding event caused by the Hurricane Agnes. This Hurricane that battered the eastern coast of the United States causing severe flooding was one in a million event. The Huricane Agnes was an unprecedented event and considered to be one of the greatest historical natural calamaties of the United States (Coasta, 1974; Gupta and Fox, 1974).

Table 2: Flood Frequency outputs using the Generalized Extreme Value Distribution for different Return Periods using the observed data from 1945 to 2016.

Return Periods (Year)	Discharge (m^3/s)
2	187.75
5	482.29
10	608.96
25	718.33
50	774.01
100	814.29
500	870.51

HEC-GeoRAS:

HEC-GeoRAS used the 1/9 arc second of DEM acquired from USGS. The raw DEM for the study area was in 4 different files which were merged using the mosaic to new raster tool in ArcGIS before processing for TIN conversion in HEC-GeoRAS. The TIN was utilized by the HEC-GeoRAS to create the river geometry outputs for HEC RAS. Total 48 cross sections were created over the reach of the study area. The consecutive meander bends of the river limited the number of cross section which can be depicted from the **Figure 2**. Later, the initially selected cross sections were modified to ensure the proper intersection with bank and flowlines. The HEC-GeoRAS user manual, (Ackerman et al., 2000), was followed throughout the analysis.

HEC-RAS analysis:

The output of the HEC-GeoRAS which comes in GIS format was imported in the HEC-RAS. Figure 2 shows a stretch of the imported cross-section of the study reach of the Patapsco River. The manning's roughness coefficient was assigned for each cross section for banks and channel as per Arcement et al., (1989) recommendation for natural rivers. The initial value of manning's roughness coefficient was chosen 0.04 for banks and 0.035 for the center of the channel. After several trails the manning's values 0.04 for banks and 0.025 for the channel resulted in good matching of model generated WSE with the observed. The manning's values were evaluated using the Nash-Sutcliffe efficiency (NSE), developed by Nash and Sutcliffe (1970). The calculated NSE value was 0.87, which was within the acceptable limit of best fit. The value of NSE ranges from ∞ to 1 and the value correspond to 1 represents a perfect match of the model and the value 0 indicates the accuracy of model prediction equal to the mean of the observed data (Nash and Sutcliffe 1970). Table 3 shows the model calibration results by comparing measured and modeled water surface level (WSE) for 1973 and 1979 floods.

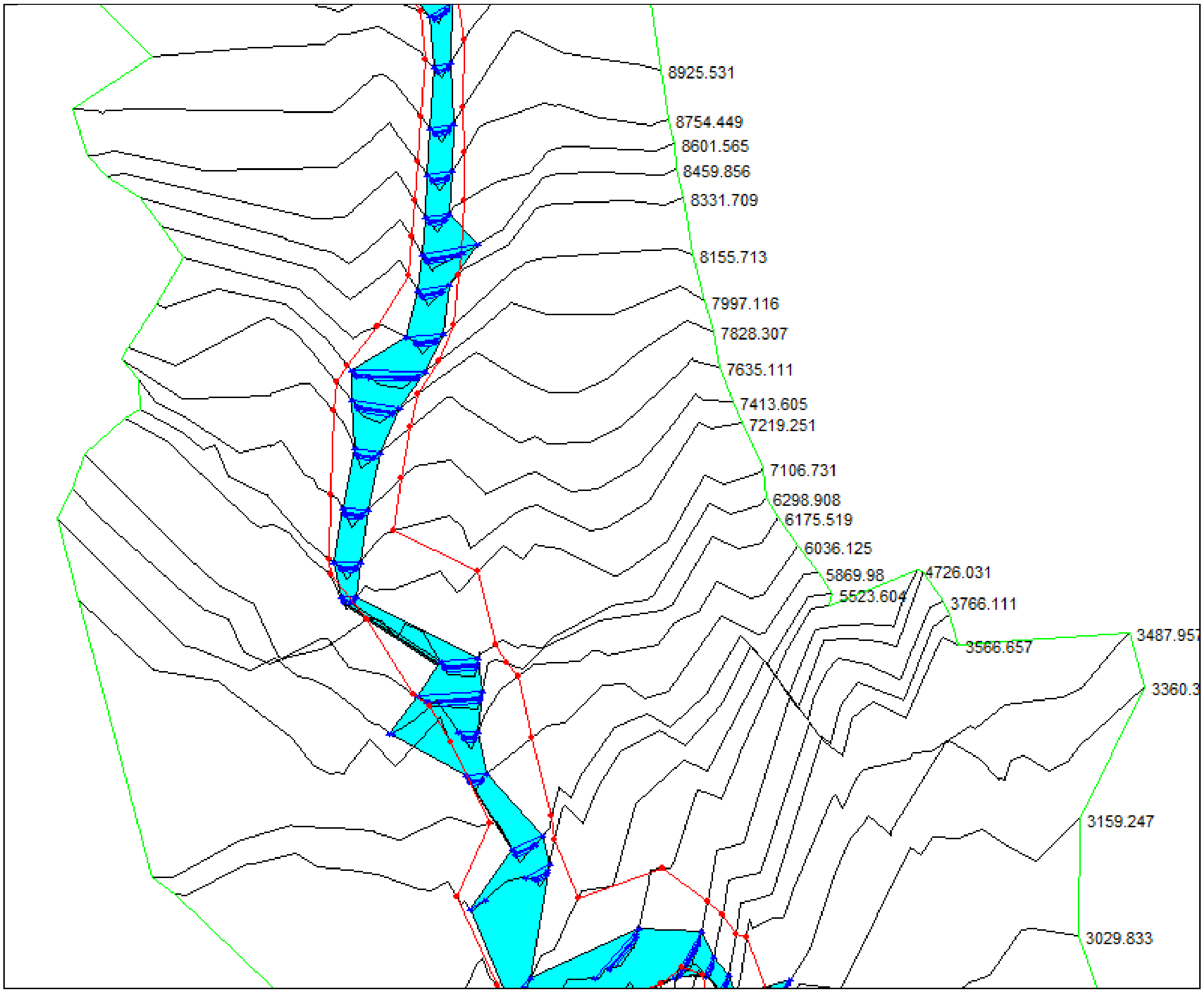

Figure 2: A stretch of the imported cross-sections from HEC-GeoRAS in HEC-RAS.

Table 3: HEC-RAS model Calibration outputs for the manning's roughness coefficient

Observed water year	Observed Discharge (m^3/s)	Observed WSE (m)	Modeled WSE (m)
1973	138.75	59.10	59.31
1979	297.33	59.87	59.94
1989	334.14	60.08	60.05
2004	419.09	60.51	60.28
2011	529.52	60.81	60.55
2015	191.70	59.18	59.55

The calibration was performed under the mixed flow analysis for the steady flow condition. The upstream and downstream slope was used for the boundary condition considering normal depth. The upstream and downstream slope was measured using the DEM and was found to be 0.005 and 0.003 for upstream and downstream, respectively. The model was then simulated for the nine different flows, seven from the statistically calculated flows for return period of 2, 5, 10, 25, 50, 100, and 500 and two historical flooding, July 30, 2016 and June 22, 1972.

Inundation Mapping in ArcGIS using HEC-GeoRAS extension:

The HEC-RAS simulated results were imported to the HEC-GeoRAS, which contains the information about water surface elevation and its extent for each flow scenario. The imported file was then processed with the TIN of the region that was created during the initial HEC-GeoRAS analysis for the river geometry. HEC-GeoRAS generated a new TIN file using the WSE information from the imported file and terrain information from initial TIN file. The new TIN file consists of flood water elevation for all the flow scenarios. Using this new TIN file HEC-GeoRAS created the extent of flood water for all flows taking single flow condition at a time. Figure 3 shows the extent of flood water after the inundating mapping for a stretch of the study area.

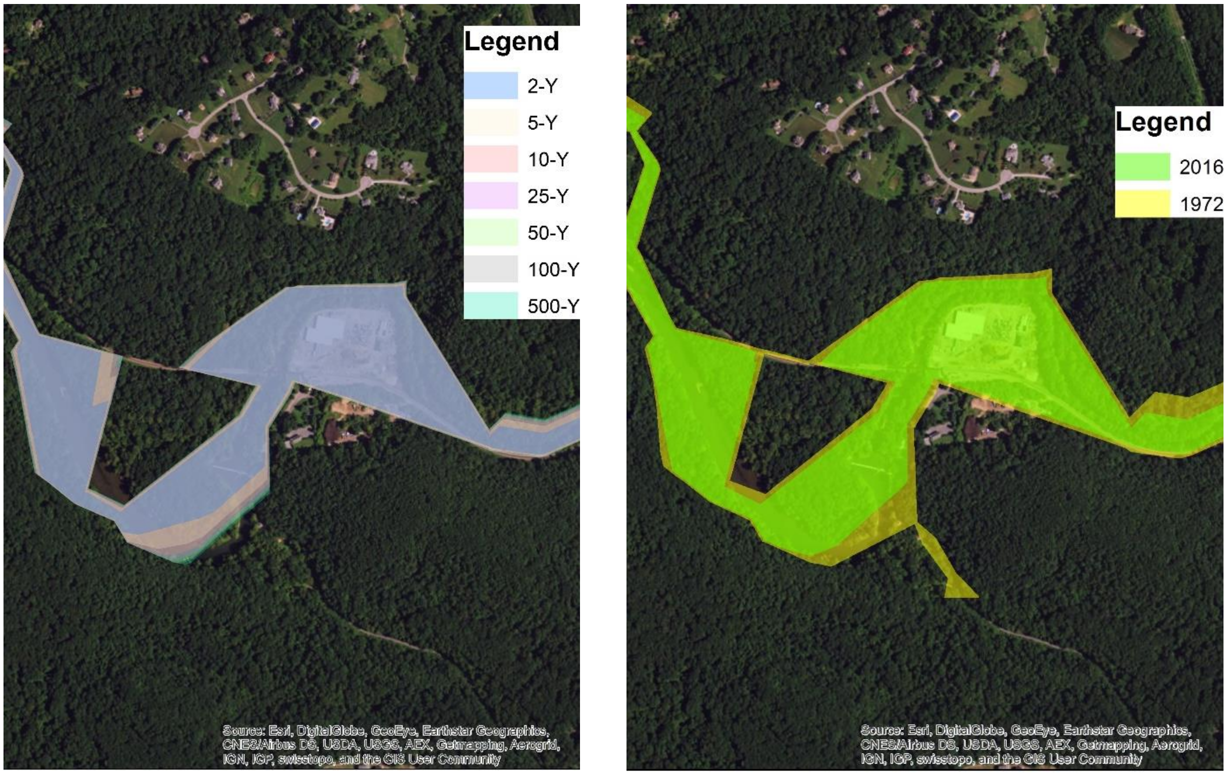

Figure 3: An Overview of inundation mapping results from HEC-GeoRAS. Left figure shows the inundated regions for the flood of 2, 5, 10, 25, 50, 100, and 500 year return period. Right figure show the inundation map resulted from two historical flooding, July 30, 2016 and June 22, 1972.

The extent of the 1972 historical flooding is greater than all other flooding condition. The results show that the 1972 flooding inundated 1.7 km^2 area while 500-year return period flow inundated 1.2 km^2 area. The extent of the 1972 flooding showed the effects of that flooding were greater than the new updated 500-year return period FEMA standard. The 1972 and 2016 historical flooding affected the most of the region of the Ellicott City, which lies near the Patapsco River stretch considered for this study. The effects were way greater than the regions depicted by the results of inundation mapping. The flooding was resulted from the heavy rainfall and the measured data were affected by the flow regulation and diversion at the upstream of the gage station. The regulation and diversion effects are highlighted in the raw data in the USGS data portal. Along with the river flooding, these historical events were made severe by the flows from the city that discharges on the downstream of the gage station. In addition to the river flood management, the Ellicott City needs an improvement in its existing stormwater system to handle the severe storms which devastate the city frequently. A method followed by Thakali et al. (2016) that considers the impact of changing climate on the stormwater infrastructure might be useful in evaluating and designing the flood management infrastructure. Thakali et al., (2016) conducted a study over the stormwater system of Las Vegas area and found it to be inadequate to handle the catchment flow in the future climate.

Summary and Conclusion

This study used the Arc GIS and HEC RAS with the aid of GIS extension HEC GeoRAS for the inundation mapping of Patapsco River near Ellicott City Maryland. 11.2 km stretch of the river was selected for the inundation mapping using different flow scenarios. With the series of recent frequent flooding events that devastated the city, the outputs of this study will be useful for the long-term flood mitigation planning, emergency action plans and different ecological studies (Ahmad and Simonovic 2006). However, this study used the terrain information from the DEM, which may not represent the most recent topography of the region. Thus, periodic change in the topography of the floodplain limits the result of this study, which can be avoided using the most recent actual survey data in the future studies. The primary conclusion drawn from this study are listed below:

1. There are some infrastructures nearby the Patapsco River that are vulnerable to the river flooding.
2. The comparison between the actual reported devastation from the historic flooding in the Ellicott City is much severe than the River flooding from Patapsco River as depicted by the inundation map resulted from this study.
3. Along with the threats from river flooding for the Ellicott City, the existing storm-water infrastructure of the city may be inadequate to handle the extreme rainfall events.

The changing climate and the increasing urbanization are resulting in more surface runoff. The modeling of floodplains is prudent for both future development and emergency response planning. The areas are vulnerable to the river flooding from the Patapsco River and require some mitigation practices. Moreover, in the severe rainfall condition, along with river flooding mitigation, the drainage infrastructures of the region need to be assessed. The drainage systems are designed for the 100-year flow, however, with recently observed flooding these structures demands a study under the climate change scenarios. This study highlighted the areas vulnerable to flooding near the Ellicott City. Results may help in the assessment of nearby infrastructure and the implementation of possible flood mitigation and evacuation strategies.

References:

Ackerman, C. T., Evans, T. A., & Brunner, G. W. (2000). “HEC-GeoRAS: linking GIS to hydraulic analysis using ARC/INFO and HEC-RAS.” *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems*. ESRI Press, New York.

Ahmad, S., & Simonovic, S. P. (2006). “An intelligent decision support system for management of floods.” *Water Resources Management*, 20(3), 391-410.

Arcement, G. J., & Schneider, V. R. (1989). “Guide for selecting Manning's roughness coefficients for natural channels and flood plains.” *US Geological Survey Water Supply Paper* 2339

Carrier, C., Kalra, A., & Ahmad, S. (2013). “Using Paleo Reconstructions to Improve Streamflow Forecast Lead Time in the Western United States.” *Journal of the American Water Resources Association*, 49(6), 1351–1366. doi:10.1111/jawr.12088.

Carrier, C., Kalra, A., Ahmad, S. (2016). “Long-range precipitation forecast using paleoclimate reconstructions in the western United States.” *Journal of Mountain Science* 13 (4), 614–632. doi:10.1007/s11629-014-3360-2.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., & Magaña Rueda, V. (2007). “Regional climate projections. Climate Change, 2007: The Physical Science Basis.” *Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, University Press, Cambridge, Chapter 11, 847-940.

Costa, J. E. (1974). “Response and recovery of a Piedmont watershed from tropical storm Agnes, June 1972.” *Water Resources Research*, 10(1), 106-112.

Colby, J., Mulcahy, K., & Wang, Y. (2000). “Modeling flooding extent from Hurricane Floyd in the coastal plains of North Carolina.” *Global Environmental Change Part B: Environmental Hazards*, 2(4), 157–168. doi:10.1016/S1464-2867(01)00012-2

Council on Environmental Quality (CEQ) (2015), "FACT SHEET: Taking Action to Protect Communities and Reduce the Cost of Future Flood Disasters." *The White House*. Available online: https://www.whitehouse.gov/the-press-office/2015/01/30/fact-sheet-taking-action-protect-communities-and-reduce-cost-future (Assessed on October 26, 2016)

Dhakal, K. P., and Chevalier, L.R. (2015). "Implementing Low Impact Development in Urban Landscapes: A Policy Perspective." *World Environmental and Water Resources Congress 2015*. (pp. 322-333). doi:10.1061/9780784479162.031

Dhakal, K.P., Chevalier, L.R. (2016). “Urban Stormwater Governance: The Need for a Paradigm Shift.” *Environmental Management*, 57(5), 1112-1124. doi:10.1007/s00267-016-0667-5

Easterling, D. R., Evans, J. L., Groisman, P. Y., & Karl, T. R. (2000). “Observed variability and trends in extreme climate events: a brief review.” *Bulletin of the American Meteorological Society*, 81(3), 417.

Ghimire, G. R., Thakali, R., Kalra, A., & Ahmad, S. "Role of Low Impact Development in the Attenuation of Flood Flows in Urban Areas." In *World Environmental and Water Resources Congress 2016* (pp. 339-349). http://dx.doi.org/10.1061/9780784479858.035

Gupta, A., & Fox, H. (1974). "Effects of high-magnitude floods on channel form: A case study in Maryland Piedmont." *Water Resources Research*, 10(3), 499-509.

Halverson, J. (2016). "This Is How an 'off-the-charts' Flood Ravaged Ellicott City." Washington Post. *The Washington Post*, 1 Aug. 2016. Available online: https://www.washingtonpost.com/news/capital-weather-gang/wp/2016/08/01/this-is-how-an-off-the-charts-flood-ravaged-ellicott-city/ (Assessed on October 26, 2016)

Hosking, J. R. M., & Wallis, J. R. (1997). "Regional frequency analysis: an approach based on L-moments." *Cambridge University Press,* Cambridge, U.K., 224.

Kalra, A., & Ahmad, S. (2011). "Evaluating changes and estimating seasonal precipitation for the Colorado River Basin using a stochastic nonparametric disaggregation technique." *Water Resour. Res*. 47, W05555. http://dx.doi.org/10.1029/ 2010WR009118.

Kalra, A., & Ahmad, S. (2012). "Estimating annual precipitation for the Colorado River Basin using oceanic-atmospheric oscillations." *Water Resources Research*, 48(6), W06527. doi:10.1029/2011WR010667.

Kalra, A., Li, L., Li, X., & Ahmad, S. (2013a). "Improving streamflow forecast lead time using oceanic-atmospheric oscillations for Kaidu river basin, Xinjiang, china." *J. Hydrological Eng*. 18 (8), 1031–1040.

Kalra, A., Miller, W. P., Lamb, K. W., Ahmad, S., & Piechota, T. (2013b). "Using large-scale climatic patterns for improving long lead time streamflow forecasts for Gunnison and San Juan River Basins." *Hydrological Processes*, 27(11), 1543–1559. doi:10.1002/hyp.9236.

King, R. O. (2005). "Federal flood insurance: the repetitive loss problem." *Library of congress Washington DC congressional research service.* Report No. RL32972.

Maheshwari, P., Khaddar, R., Kachroo, P., & Paz, A. (2014). "Dynamic Modeling of Performance Indices for Planning of Sustainable Transportation Systems." Networks and Spatial Economics, 1-23.

Mosquera-Machado, S., & Ahmad, S. (2007). "Flood hazard assessment of Atrato River in Colombia." *Water Resources Management*, 21(3), 591-609.

Nash, J. E., & Sutcliffe, J. V. (1970). "River flow forecasting through conceptual models part I—A discussion of principles." *Journal of hydrology, 10*(3), 282-290.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., & Dubash, N. K. (2014). "Climate change 2014: synthesis report." *Contribution of Working Groups I, II* *and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). IPCC.

Chicago

Pathak, P., Kalra, A., & Ahmad, S. (2016a). “Temperature and precipitation changes in the Midwestern United States: implications for water management.” *International Journal of Water Resources Development*, 1-17, http://dx.doi.org/10.1080/07900627.2016.1238343

Pathak, P., Kalra, A., Ahmad, S., & Bernardez, M. (2016b). “Wavelet-Aided Analysis to Estimate Seasonal Variability and Dominant Periodicities in Temperature, Precipitation, and Streamflow in the Midwestern United States.” *Water Resources Management*, 30(13), 4649-4665. http://doi.org/10.1007/s11269-016-1445-0

Pathak, P., Bhandari, M., Kalra, A., & Ahmad, S. (2016c). “Modeling Floodplain Inundation for Monument Creek, Colorado.” *In World Environmental and Water Resources Congress* (pp. 131-140).

Paz, A., P. Maheshwari, P. Kachroo, & S. Ahmad (2013). “Estimation of performance indices for the planning of sustainable transportation systems.” *Advances in Fuzzy Systems*, 2.

Sagarika, S., Kalra, A., 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. doi:10.1016/j.jhydrol.2014.05.002.

Sagarika, S., Kalra, A., Ahmad, S. (2015a). “Interconnection between oceanic-atmospheric indices and variability in the US streamflow.” *Journal of Hydrology* 525, 724–736. doi:10. 1016/j.jhydrol.2015.04.020.

Sagarika, S., Kalra, A., Ahmad, S. (2015b). “Pacific Ocean and SST and Z500 climate variability and western U.S. seasonal streamflow.” *International Journal of Climatology 36*, 1515–1533. doi:10.1002/joc.4442.

Rector, K. (2016). "2 Dead, Emergency Declared after Historic Ellicott City Ravaged by Flash Flood." *Howard County Times*, 01 Aug. 2016 Available online: http://www.baltimoresun.com/news/maryland/howard/ellicott-city/bs-md-ellicott-city-flood-20160731-story.html (Assessed on October 26, 2016)

Tamaddun, K., Kalra, A., Ahmad, S. (2016a). “Identification of Streamflow Changes across the Continental United States Using Variable Record Lengths.” *Hydrology*, *3*(2), 24. http://doi.org/10.3390/hydrology3020024.

Tamaddun, K. A., Kalra, A., Ahmad, S. (2016b). “Wavelet analysis of western U.S. streamflow with ENSO and PDO.” *Journal of Water and Climate Change*, 1–15. http://doi.org/10.2166/wcc.2016.162

Thakali, R., P., Kalra, A., Ahmad, S. (2016). “Understanding the Effects of Climate Change on Urban Stormwater Infrastructures in the Las Vegas Valley.” *Hydrology*, *3*(4), 34, Doi:10.3390/hydrology3040034

U.S. Army Corps of Engineers (USACE) (1991). HEC-2, Water Surface Profiles, User's Manual, Hydrologic Engineering Center, Davis, California, USA.

United States Geological Survey, (USGS). (2012). “U.S. Geological Survey Flood Inundation Initiative: Prospectus.” Available online: http://water.usgs.gov/osw/flood_inundation/index.html (Assessed on October 26, 2016)