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Coupling HEC-RAS and HEC-HMS in precipitation runoff modelling and evaluating flood plain inundation map.

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**ABSTRACT**

The climate change and land use change have raised the challenges associated with increased runoff and flood management. The risks associated with flooding have been increasing with development in flood plain and changing climate resulting in increase in inundation of flood plain. The current study will help to evaluate the extent of flood plain in the study area – Copper Slough Watershed (CSW) in Champaign, Illinois; utilizing the known precipitation and land use. The study of CSW is taken into account, as this is the largest watershed of Champaign City and had undergone major land use change increasing the flooding issues in the region. The conducted research utilizes the Hydrologic Engineering Center - Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center – River Analysis System (HEC-RAS) as the modelling tool to develop runoff and floodplain inundation evaluation model for known precipitation. The model also incorporates Aeronautical Reconnaissance Coverage Geographic Information System (ARCGIS) extensions- HEC-GeoRAS and HEC-GeoHMS for the spatial analysis of the watershed. The hydrologic analysis is performed using HEC-HMS while the hydraulic modeling is done using HEC-RAS. Forcing the model with forecasted precipitation can also help with flood warning system by generating pre-flood inundation maps.

Keywords: Rainfall-Runoff Model, HEC-HMS, HEC-GeoHMS, HEC-RAS, HEC-GeoRAS

## INTRODUCTION

The changing climate in the past century is quite convincing based on several studies (IPCC, 2014a; Carrier et al., 2016). In the period from 1951 to 2012, global temperature increased at the rate of 0.8℃ to 0.14℃ (IPCC, 2014a). Climate change has led to increasing temperature in some places while increasing precipitation and streamflow at the other places (Kalra and Ahmad, 2011, 2012; Pathak et al., 2016a). The changing climate is a driver that induces the shifts in hydrological regimes by changing different parameters of hydrologic cycle such as precipitation and evaporation (Middelkoop et al., 2001; Kalra et al., 2013 a&b; Pathak et al., 2016b). Change in precipitation that results in changes in streamflow can hence be linked to change in climate indices (Tamaddun et al., 2016a; Sagarika et al., 2014). Streamflow changes in US has been attributed to ocean climatic variability in some studies highlighting the impact of climate change (Sagarika et al., 2015a,b). The impacts of variation in climate differs regionally inducing droughts in some region while in other region intensifying precipitation and runoff (Middelkoop et al., 2001; IPCC, 2014b; Tamaddun et al., 2016b). In addition to climate change, the changes in land use and urbanization increase the non-pervious area resulting in increasing the runoff from the watershed by reducing the infiltration (Parker, 2000; Sohn et al., 2015; Thakali et al., 2016). Thus, the flood events are accompanied by the change in land use and intensification of storms due to climate change. The study conducted by Red Cross in 2010 (WDR, 2010) suggests 99 million peoples affected by flood hazards worldwide. Assessments of flood affected areas resulting from extreme precipitation and changing land use can be helpful in better understanding the flood events (Ahmad and Simonovic, 2006; Mosquera-Machado and Ahmad 2007; Dawadi and Ahmad 2012).

Assessment of the extent and depth of floods has been one of the prime goals for the water resource managers for making policies for mitigation of flood impacts. Such an assessment is also critically important to inform the public and policy makers and garnering their support for making such policies and structuring a suitable governance (Paz et al, 2013; Maheswari et al., 2014; Dhakal and Chevalier 2015, 2016). Physical models take into account the underlying parameters of the system being simulated and are able to simulate the results based on the changes in the key driving parameters. Motivated with the conducted literature review, current study develops the physical model to mimic the rainfall runoff event with the aid of hydrologic and hydraulic feature of Hydrologic Modelling System (HEC-HMS) and Hydrologic Engineering Center – River Analysis System (HEC-RAS), respectively. Previously, Knebl et al., (2005); Yuan and Qaiser (2011) and Tahmasbinejad et al., (2012), have coupled HEC-HMS and HEC-RAS modelling tools. Current study couples these tools with Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) extensions, Geographic hydrological model extension (HEC-GeoHMS) and Geographic River Analysis extension (HEC-GeoRAS) for generating the input model data from the available data in digital format for HEC-HMS and HEC-RAS, respectively.

Precipitation is the only source of runoff and flood in the one or other form but the transformation of the runoff from precipitation is governed by the parameters such as land use, soil type, evaporation, and storage. HEC-HMS deals with the basic water balance equation taking into account major parameters that governs runoff and is capable of modelling rainfall runoff event. While, HEC-RAS can simulate the runoff hydraulics through the channel based on the channel morphology and can generate the extent of the inundated region. Coupling these two models can assess the inundated region for a known storm event. Further, the calibrated coupled model can be used for future flood plain mapping with the future rainfall data and land use scenarios.

## STUDY AREA AND DATA

Illinois receives average annual precipitation of around 48 inches and flooding is a major hazard of this state. Copper Slough Watershed (CSW) is situated in central region of Illinois in terms of latitude. Most of the region of CSW falls in the Champaign city with high imperviousness and moreover three interstate highways are also located in this watershed resulting the high runoff per unit area for a given storm event. Taking above mentioned aspects into consideration CSW is incorporated as the study area in the current research. The precipitation data for the watershed was abstracted from the USGS station 05590050. The precipitation station along with the CSW is shown in Figure 1. The discharge data from the watershed along with the gage heights were obtained from the same USGS station as precipitation data. The area of the delineated watershed with the outlet at the selected gaging station was obtained to be 15.92 sq.km. The terrain data, soil type and land use data is tabulated in Table: 1 along with the website from where they were abstracted.

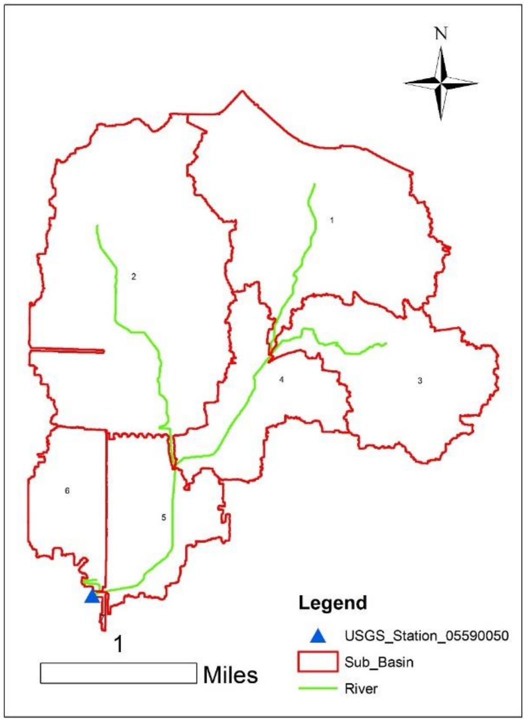


Fig: 1. Study area of Copper Slough Watershed with 7 sub basins, streams, and USGS rainfall and runoff gaging station.

Table: 1 Input Data for the rainfall runoff model along with the source from where they were abstracted.

| SN | Data | Data source |
|---|---|---|
| 1. | 1/9 arc second Digital elevation model (DEM) | United States Geological Survey (USGS) National map viewer. Website: https://viewer.nationalmap.gov/basic/ |
| 2. | Land use data 2011 | National Land Cover Database (NLCD) website: www.mrlc.gov |
| 3. | Soil type Data | Soil Survey Geographic Database (SSURGO) Website: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx |
| 4. | Rainfall, Runoff , Gage Height data | USGS station site inventory for station ID 05590050 Website: http://waterdata.usgs.gov/nwis/inventory |

**METHODOLOGY**

The model structure is shown in Figure 2 showing the coupling of the model components used in the study. First the runoff is obtained from the precipitation data with HEC-HMS model. The obtained runoff is then simulated in HEC-RAS. The output of HEC-RAS is then exported to HEC-GeoRAS for flood plain mapping. In this section first, HEC-HMS modelling approach along with the generation of input file of HEC-HMS with HEC-GeoHMS is discussed followed by the modelling approach in HEC-RAS and generating HEC-RAS inputs with HEC-GeoRAS is briefly described. Lastly, the section also elucidates the mapping of the flood plain with HEC-RAS results in HEC-GeoRAS.

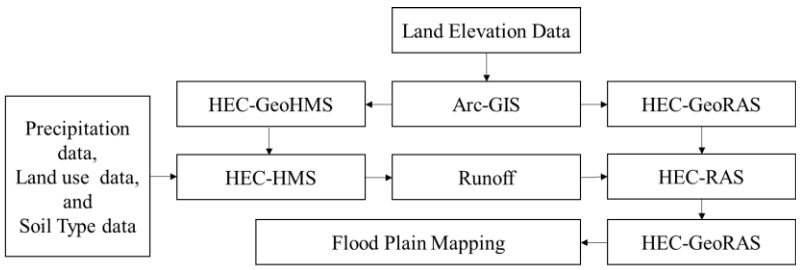


Fig: 2. Modelling structure of rainfall-runoff model for generating floodplain inundation map incorporating HEC-HMS, HEC-RAS along with Arc-GIS extensions HEC-GeoHMS and HEC-GeoRas.

The input data for HEC-HMS was generated with HEC-GeoHMS which incorporates spatial analyst and other features of Arc-GIS. Digital Elevation Data was used in HEC-GeoHMS for generating drainage paths and sub basins along with other features such as sub basin slope and area, drainage path slopes, and longest flow paths of sub basin. These parameters were then used as input for HEC-HMS. The generated HEC-HMS model is shown in Figure 3. The runoff of CSW is mainly generated by the precipitation, thus the base flow of the watershed was neglected. Soil Conservation Service (SCS) curve number is implemented for the precipitation loss calculations. The curve number for each sub basin was generated with the land use and soil type data. The land use data obtained from NLCD were reclassified in Arc-GIS into four major groups based on Land Cover Institute (LCI) as tabulated in Table: 2. While runoff transformation from precipitation was conducted using SCS unit hydrograph method and the routing of the flow from the outlet of each sub-basin to the outlet of entire watershed was achieved using Muskingam-Cunge method.

Table: 2. Reclassified CN look up table for Copper Slough watershed based on classifications of USGS Land Cover Institute (LCI) 2001.

| SN | Soil Type | Type of Land Use | | | |
|---|---|---|---|---|---|
| | | Water | Medium Residential | Forest | Agriculture |
| 1 | A | 100 | 57 | 30 | 67 |
| 2 | B | 100 | 72 | 58 | 77 |
| 3 | C | 100 | 81 | 71 | 83 |
| 4 | D | 100 | 86 | 78 | 87 |

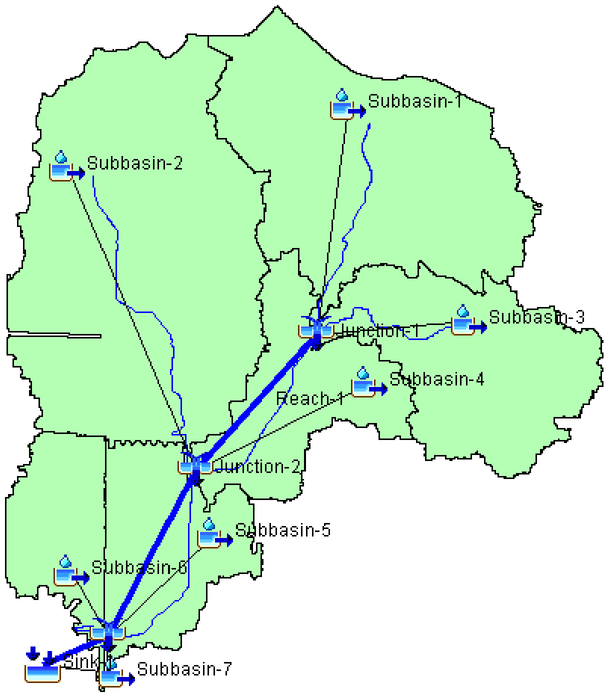


Figure: 3. HEC-HMS model for Copper Slough Watershed showing modelled sub-basin, junction, reach, and sink.

While generating HEC-RAS geometric input data using HEC-GeoRAS first, the Triangular Irregular Network (TIN) data was obtained from the available USGS DEM data using 3D analyst of Arc GIS. After generating TIN, the river was digitized in HEC-GeoRAS. Figure 4. shows the digitized river geometry for the CSW upstream to the USGS station 05590050 in HEC-GeoRAS. For this, the layers were created for stream centerlines, bank lines, flow path lines, and (cross section) XS cut lines. In editor mode each layers were then digitized. The attributes for all layers were computed and the data was then exported to HEC-RAS. GIS data was then imported in HEC-RAS from the geometry window of HEC-RAS. The cross sections generated in GIS were observed as stations numbers from downstream station to upstream station in the cross section editor window of HEC-RAS (Tate, 1999). HEC-RAS model was then run for different observed discharges and gage heights from USGS stations 05590050 at the downstream of the river reach. The calibration was conducted by changing the manning's n to get the simulated depth of flow same as the depth measured at the gaging station. The calibrated model was then validated for different events that were used for calibration. The simulated runoff from HEC-HMS was then used in the calibrated and validated HEC-RAS model to generate the inundation extent and the water surface elevation. The flood plain map showing the inundation extent was generated with HEC-GeoRAS by exporting the HEC-RAS results to HEC-Geo RAS.

Figure: 4. Digitized geometry of the simulated Copper Slough River length in HEC-GeoRAS using TIN. Green lines show the crossections, red lines are the river bank lines, and blue lines represent centerline of stream and flow path lines.

**RESULTS AND DISCUSSION**

The results of simulated runoff for the precipitation event were obtained from HEC-HMS and the flood plain model was generated with the aid of HEC-RAS and HEC-GeoRAS. The water surface profiles, discharges and velocities along with Froude number at different cross sections were obtained with the aid of HEC-RAS

HEC-HMS results

Based on the land use data and the soil type data the computed weighted area curve number for each sub basin of CSW is shown in Table 3. The simulated runoff obtained using curve number for the storm of 25$^{th}$ June 2015 was lower than the observed value demanding the calibration of the model. The lower prediction in the runoff can be explained as the change in land use since 2011 resulting the change in lag time and time of concentration due to the variations in curve number. The model was calibrated to reduce the error in lag time by changing the curve number. Manning's n of the reaches were also tweaked for the calibration and for the model it was observed that the model was more sensitive to the curve number than the values of manning's n considered for all reaches. The calibration of the model was done for the 8$^{th}$ July 2015 storm and the validation was conducted for the storm of 25$^{th}$ June 2015. The calibration and validation period was selected with the recent peak events so, the recent changes in the physiology of the watershed could be taken into account. The model simulated runoff for the storm events 8$^{th}$ July 2015 and 25$^{th}$ June 2015 was reported to be 6.7 m$^3$/s (236.6 cfs) and 16.1 m$^3$/s (568 cfs), respectively. While the corresponding observed discharge was 6.7 m$^3$/s (181cfs) and 20.08 m$^3$/s (709cfs). The calibrated curve number is reported in Table 3.The simulated discharge for 25$^{th}$ June 2015 is used as an input for HEC-RAS. The results obtained from HEC-HMS can be further refined by considering the base flow and other sources of runoff except rainfall. Different loss methods other than SCS curve number and the routing method other than Muskingam-Cunge method can be incorporated to improve the results. While calibrating, the CN increased by significant amount in Table 3, similar to Ghimire et al., (2016), because not accounting for other losses and error in method of routing and loss calculations were balanced by calibration of CN.

Table: 3 Initial and calibrated Curve Number for each sub-basins

| Sub Basin | Initial curve number | Calibrated curve number |
|---|---|---|
| 1 | 68.16 | 95 |
| 2 | 62 | 92 |
| 3 | 66.37 | 90 |
| 4 | 70.17 | 95 |
| 5 | 58.4 | 88 |
| 6 | 58.88 | 89 |
| 7 | 57 | 77 |

HEC-RAS results

The peak flow predicted by the HEC-HMS model is taken as the steady flow in HEC-RAS. The water surface elevation in the downstream cross section is shown in Figure 5 for the storm of 25$^{th}$ June 2015. The length in both axis in the figure are in m. The model was then calibrated for different flows and USGS gage height data at the most downstream cross section. The extent of inundation for the flood event of 25$^{th}$ June 2015 is shown in Figure 6. The extent of flood is larger than the river cross section for the storm event of 25$^{th}$ June 2015 as seen in the Figure 7. Thus, it can be asserted that there is chances of the flooding for the peak events with higher return period under the scenario of continuously changing land use because of the growth of the city. The flooding in the city of Campaign can cause losses so for better management of the water resources best management practices should be taken into account to mitigate the impact of land use change due to urbanization and reduce the extent of flooding. The inundation extent signifies that climate is changing and also supports IPCC (2014b) findings of climate change and increasing flooding risks. There are some associated uncertainty in calibrating the roughness based on downstream level observation; for more details on calibration uncertainty in HEC-RAS users are referred to Pappenberger et al., (2005).

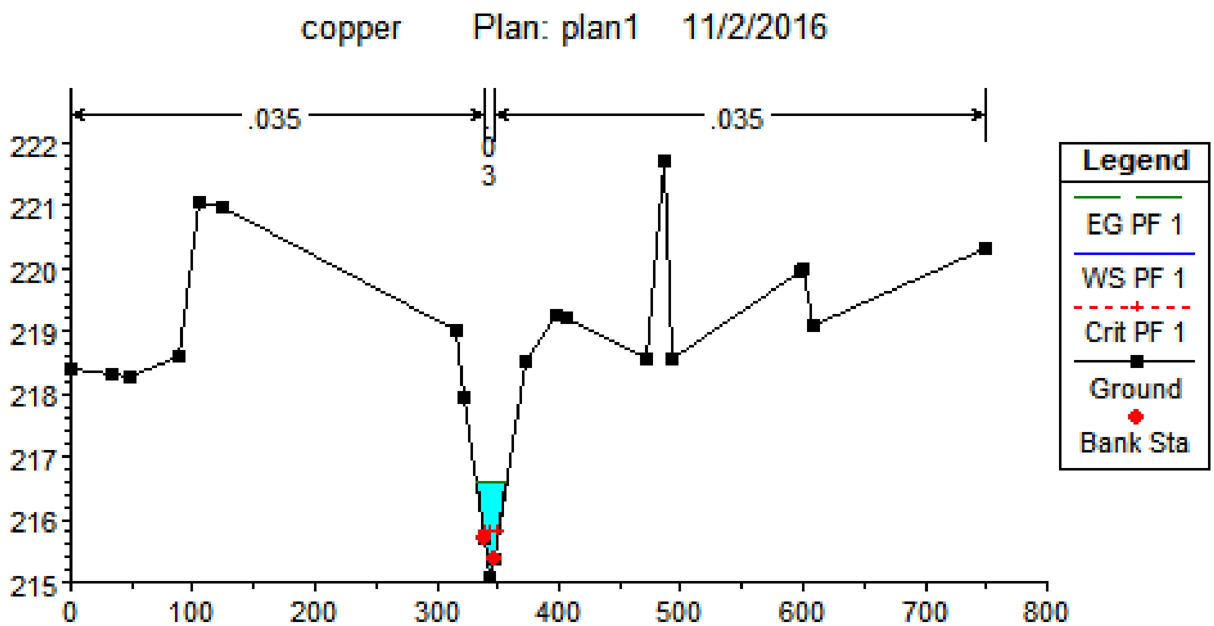


Fig 5: HEC-RAS results for the simulated downstream cross-section of the Copper Slough River for 25th June 2015 event. X-axis and Y-axis are in meters.

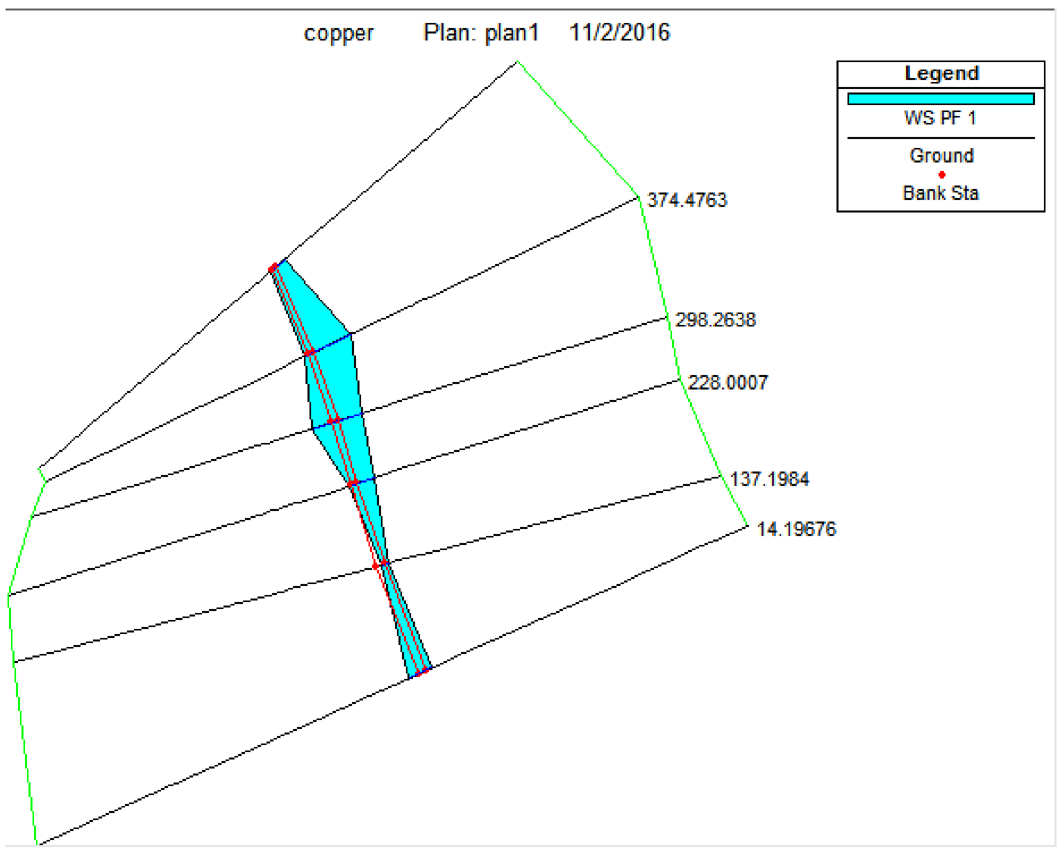


Fig:6. Plan view of simulation results of the flow in HEC-RAS for 25th June 2015 event


Fig: 7. Flood plain mapping upstream of USGS station 05590050 in the copper slough watershed.

**Conclusion:**

The current study is summarized with the following points.

1. The main intent behind the study was to develop a rainfall runoff model to generate the flood inundation extent for the known precipitation event.
2. Future precipitation predictions can be used in the current model for the generation of future flood inundation maps and assessing the peak flood in future.
3. The model is not region sensitive, similar model can be developed for other catchments for the assessment of flood magnitude and its extent.

The HEC-HMS model was calibrated by tweaking the curve number and manning's n and the model sensitivity to curve number is high as compared to that of manning's n. The transformed runoff with the help of HEC-HMS are used for flood plain mapping with HEC-RAS. The generated inundation map is the model prediction for the peak flow of 2015. The region is expected to flood to greater extent if the rainfall event is more intense and of shorter duration as compared to the considered event. To mitigate the flooding and reduce the flood extent, best management practices such as low impact development can be adopted.

No model is complete and there is always scope of refining the model. Current model can be refined by incorporating higher resolution data, and including recent data and scenarios. Considering more refined survey data such as Light Detecting and Ranging using Remote Sensing Data (LIDAR) data can improve the model. The current model was calibrated based on the land use data for 2011, thus more recent land use data incorporation can further refine the model. This model can be improved to get future flooding extent by incorporating future precipitation data based on the predictive models such as North American Regional Climate Change Assessment Program (NAARCAP) data.

**References**


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

Carrier, C. A., Kalra, A., & Ahmad, S. (2016). "Long-range precipitation forecasts using paleoclimate reconstructions in the western United States." *Journal of Mountain Science*, *13*(4), 614-632.

Cross, R. (2010). "World Disasters Report 2010-Focus on Urban Risk." *International Federation of Red Cross and Red Crescent Societies, Geneva*.

Dawadi, S., & Ahmad, S. (2012). "Changing climatic conditions in the Colorado River Basin: implications for water resources management." *Journal of Hydrology*, *430*, 127-141.

Dhakal, K.P., Chevalier, L.R. (2015). "Implementing Low Impact Development in Urban Landscapes: A Policy Perspective." World Environmental and Water Resources Congress 2015. *American Society of Civil Engineers*, 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

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

IPCC, 2014a: "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* [Core Writing Team, R.K. Pachauri, R.K., & Meyer, L.A. (Eds.)]. IPCC, Geneva, Switzerland, 151 pp

IPCC, 2014b: “Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.” *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, S., MacCraken, S., Mastrandrea, P.R., & White, L.L. (Eds.)]. Cambridge University Press, Canmbridge, United Kingdom and New York, NY, USA, pp.688.

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.

Knebl, M.R., Yang, Z. L., Hutchison, K., Maidment, D.R., 2005. “Regional Scale Flood Modeling using NEXRAD Rainfall, GIS, and HEC-HMS/RAS: A case study for the San Antonio River Basin Summer 2002 storm event.” *Journal of Environmental Management 75, 325–336.*

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.

Middelkoop, H., Daamen, K., Gellens, D., Grabs, W., Kwadijk, J. C., Lang, H., & Wilke, K. (2001). “Impact of climate change on hydrological regimes and water resources management in the Rhine basin”. *Climatic change*, *49*(1-2), 105-128.

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

Pappenberger, F., Beven, K., Horritt, M., & Blazkova, S. (2005). “Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations.” *Journal of Hydrology, 302(1), 46-69.*

Parker, D. J. (2000). “Floods, volumes I and II”. *London and New York: Routledge.*

Pathak, P., Kalra, A., Ahmad, S., & Bernardez, M. (2016a). “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., Kalra, A., & Ahmad, S. (2016b). "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

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). "Interconnections 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 SST and Z500 climate variability and western US seasonal streamflow." *International Journal of Climatology*. *36*, 1515– 1533. doi:10.1002/joc.4442.

Sohn, W., Kim, J. H., & Li, M. H. (2015) "Low Impact Development Applications in Urban Watersheds: Efficacy Evaluation by Imperviousness Connectivity Estimations".

Tahmasbinejad, H., Feyzolahpour, M., Mumipour, M., & Zakerhoseini, F. (2012). "Rainfall-runoff simulation and modeling of Karun River using HEC-RAS and HEC-HMS models, Izeh District, Iran." *Journal of Applied Sciences, 12(18), 1900.*

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 US streamflow with ENSO and PDO." *Journal of Water and Climate Change*, 1–15. http://doi.org/10.2166/wcc.2016.162

Tate, E. C., & Maidment, D. R. (1999). "*Floodplain mapping using HEC-RAS and ArcView GIS"* (Master's thesis, University of Texas at Austin).

Thakali, R., 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.

Yuan, Y., & Qaiser, K. (2011). "Floodplain Modeling in the Kansas River Basin Using Hydrologic Engineering Center (HEC) Models: Impacts of Urbanization and Wetlands for Mitigation". *US Environmental Protection Agency, Office of Research and Development.*