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Urbanization and Its Potential Impact on the Peak Discharge from the Watershed of the Upper Merced River in California

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Abstract
Urbanization is an unavoidable process that influences many components of a watershed, and thus hydrologic processes are severely affected by changes in land use due to this urbanization. During this study, the objective was to assess the impact of urbanization on the peak discharge of a watershed in accordance with the outcome of this research. For this purpose, Watershed Modeling System (WMS) software and Hydrologic Engineering Center- Hydrologic Modeling System (HEC-HMS) model were used for simulating various land-use scenarios of Merced County, in the central part of California, USA. Simulation results were analyzed to assess the impact of land-use changes on the peak discharge of the watershed. The results showed that approximately 18% peak discharge was increased at the sub-basin level and approximately 2% peak discharge was increased at the final outlet. In the future, the study could help researchers, policymakers, and structural designers to foresee and prevent the unpleasant effects of urbanization so that they can take specific measures to prevent calamities beforehand.
Keywords: Watershed-modeling, urbanization, land use, peak discharge, WMS, HEC-HMS.
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1. Introduction

The major benefit of watershed modeling is to provide comprehensive and systematic assessment of water quantity at a geographic scale which is useful for the development, project planning, effectiveness monitoring, and protection strategies. Watershed is an area of land that drains downslope to the lowest point of elevation. Water moves through a network of drainage pathways, both underground and on the surface (Ponce, 1997). Generally, these pathways converge into streams which become gradually larger as the water moves on downstream, and ultimately reaching to the ocean. Watersheds can be large or small. Small watersheds join together and make larger watershed. It is relatively easy to delineate watersheds using a topographic map that shows stream and channels. There are several computer-based watershed modeling techniques.

Hydrologic model is a type of tool, used in combination with many other assessment techniques. Watershed modeling reflects our understanding of watershed systems at its outlets. As with any tool, this tool could be used for strategic planning, flood control, water management and urban planning (Ponce, 1997). It can also be used for wastewater allocation, resource management and ecological restoration. In order to perform watershed modeling it is necessary to understand the background theories and functions behind it. This paper identified and reviewed current technologies and issues involved with performing hydrologic modeling at the Upper Merced River watershed in California, USA. The main objective was to evaluate the impact of land use changes (urbanization) on hydrologic processes especially on peak discharge of the studied watershed.

2. Literature survey

2.1 Watershed Modeling:

A watershed model provides a more complete and systematic assessment of water quality at a geographic scale useful for the development and implementation of project planning, effectiveness monitoring, and protection strategies. A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small or field-scale without full incorporation of a watershed area (Oogathoo, 2006). Different types of watershed models are available and their use depends on their specific purpose.

2.2 HEC-HMS:

HEC-HMS (Hydrologic Engineering Center-The Hydrologic Modeling System) was developed to simulate hydrologic processes (precipitation, losses, baseflow, runoff transformation, and routing) on watersheds, produces runoff hydrographs at single or multiple locations on complex watershed (Feldman, 1995). HEC-HMS is the "next generation" model which is a Windows-based model for precipitation-runoff simulation. HEC-HMS provides a variety of options for simulating precipitation-runoff and routing processes (Bennie *et al.* 1997), integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities (Scharffenberg, 2008). This model is widely used for modeling floods and impacts on land use changes (Oogathoo, 2006).

2.3 Watershed Modeling System (WMS):

WMS was developed by Environmental Modeling Systems, Inc. at Brigham Young University, USA is a comprehensive graphical modeling setting for all phases of watershed (Aquaveo, 2015). It is a powerful tool which can automatically delineate basin, calculate geometric parameter and curve numbers (CN), rainfall depth, roughness coefficients, etc. WMS provides an interface for a variety of hydrologic and hydraulic models within a GIS-based processing framework. Models packaged within the system include HEC-1, TR-20, TR- 55, as hydrologic modeling components. Additional calculations include use of the rational method to compute peak flows primarily for small rural watersheds (Aquaveo, 2015).

2.4 Curve Number method

The Curve Number Method is used to determine the amount of direct runoff for a particular rainfall event. Due to its simplified application it is wide used (Francesco and Giovanni, 2010). Natural Resources Conservation Service developed this method in the 1950s for national usage (Woodward *et al.* 2013). This method takes account of watershed features such as soil type, field usage and refining, surface circumstance, and existence and amount of moisture (Mishra and Vijay, 2003). The general equation for the SCS curve number method is as follows equation (U.S. Army Corps of Engineers Hydrologic Engineering Center 1994):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where;

Q = runoff
P = rainfall
S = potential maximum retention after runoff begins
Ia = initial abstraction

It is affected by land use and land cover have become key to many diverse applications such as agriculture, environment, ecology, forestry, geology, and hydrology (Weng, 2001). Discharge is also influenced by the change of land cover, land use, surface runoff etc. Therefore, assessment of land cover and land use models and their impact on watershed level is essential for planning and management of water resources and land use of the specific watershed.

3. Problem definition

The main aim of this study is to know "does urbanization have any impact on watershed hydrologic processes, especially peak discharge? If yes, how does it effect on peak discharge in a watershed?" The specific objectives of the study are to:

1) delineate the Upper Merced River watershed using SCS curve number method;
2) create a HEC-HMS watershed model using WMS; and
3) impact of varying levels of urbanization on the watershed.

4. Methodology

4.1 Project Location

The study area is located in the northern part of Merced County, in the central part of California, USA. The study area is a part of Upper Merced River Watershed (Figure 1). The average elevation of the area is 527 m above the sea level. The mean annual precipitation of the area is 250 mm and mean annual temperature is 18°C (Villa and Ryals, 2021). Land use within the watershed is predominantly evergreen forested land and barren land (Figure 2). Usually people use the area for recreational purposes. However, with increasing urbanization there is growing demand of commercial and services land.

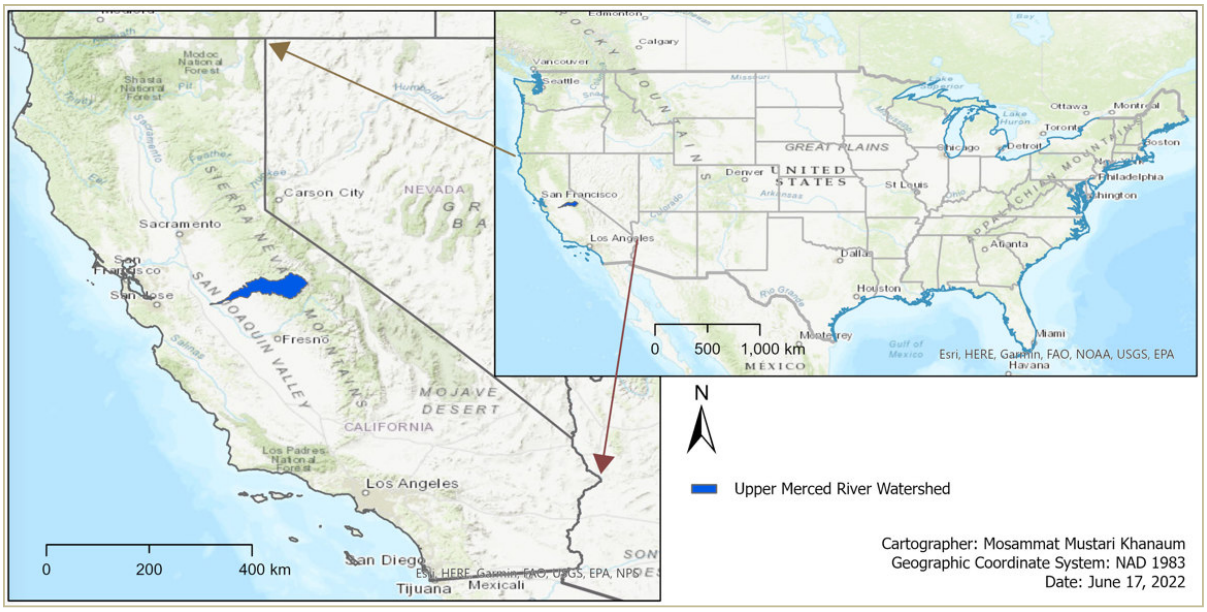

Figure 1: Location of Upper Merced River Watershed

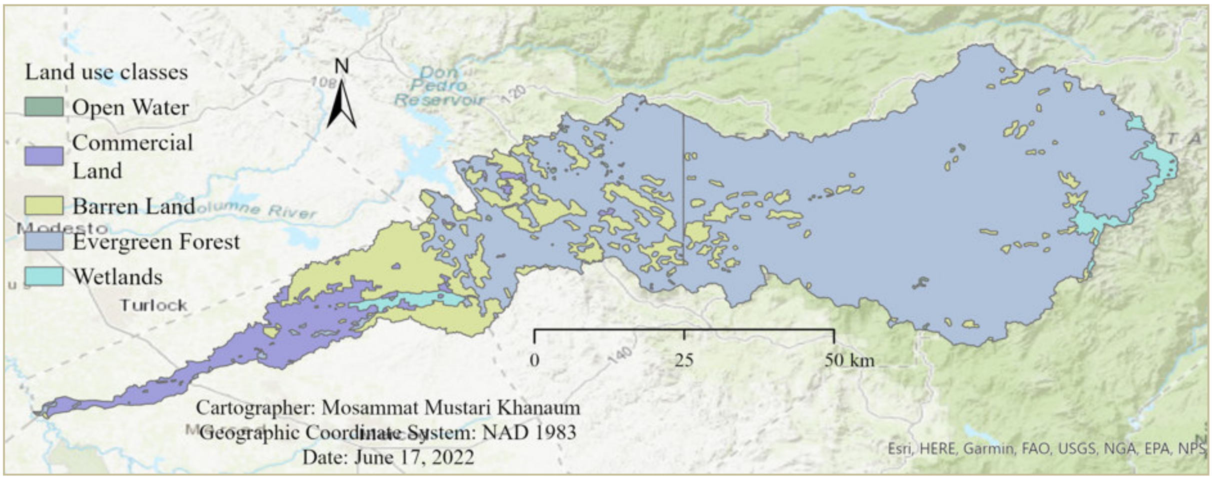

Figure 2: Land use classes of the study area, Upper Merced River watershed.

4.2 Modeling process

WMS V10.0 and HEC-HMS V4.0 was used to delineate the watershed and for different land use scenario analysis. Soil Conservation Service (SCS) curve numbers method was used for runoff estimation. ArcGIS Pro V2.9.1 was used for visualization of the watershed boundary and land use classes of the study area. All useful inputs for the research were collected from different US federal websites (Table I).

Table I: Sources of different data used in the study

Data	***Description***	***Source***
Digital Elevation Model	DEM for Merced, CA	USGS national map viewer
Land Use Land cover	Shapefile	NRCS Geospatial data gateway
Soil Type	Shapefile	NRCS Geospatial data gateway
Precipitation	100-yr 24-hr Rainfall data	NOAA and WinTR-55
8-digit Hydrologic Unit Code	HUC8 number 18040008	U.S. Geological Survey

The watershed was delineated using WMS (Figure 3). A 30m Digital Elevation Model (DEM) was re-projected to NAD_1927_TUM_Zone_10N. A smaller part of the Merced River basin was selected for the study. All the land use, land cover, and soil data were added and overlaid with the DEM. Before that soil hydro-group was added by joining the *statsgoc.dbf* file to the layer geoprocessing tool. Flow direction/accumulation was done using Run *Topaz* function in WMS and the watershed was divided into seven sub-basins (Figure 4). After delineation of basins, curve numbers were calculated for all sub-basins. Type-1 storm was selected for the study as Merced county, California is located at type-1 storm zone of USA. In addition, other required parameters pertinent for HEC-HMS simulation model such as loss method for separating precipitation volume from runoff excess, transform method for simulating the process of direct runoff of excess precipitation, Time of Concentration and Lag time were determined by using WMS. Furthermore, CN numbers for different land uses were determined by WinTR-55 method. SCS curve number method for determining runoff, SCS for transform method and recession baseflow method were selected for all sub-basins and lag routing method was selected for reaches. Finally, in order to evaluate the urbanization impact on watershed discharge, different scenarios (Table II) were run in WMS. Sub-basin 4B was selected for that purpose. The output of WMS was used as the input of HEC-HMS for further simulation.

Table II: Description of model simulations for different scenarios

Model Simulation	***Description of different scenario***
Simulation-1	Simulation with existing condition
Simulation-2	Reducing 10% Evergreen Forest Land (group D) and substituting the land with Commercial & Services at sub-basin 4B
Simulation-3	Reducing 20% Evergreen Forest Land (group D) and substituting the land with Commercial & Services at sub-basin 4B
Simulation-4	Reducing 30% Evergreen Forest Land (group D) and substituting the land with Commercial & Services at sub-basin 4B

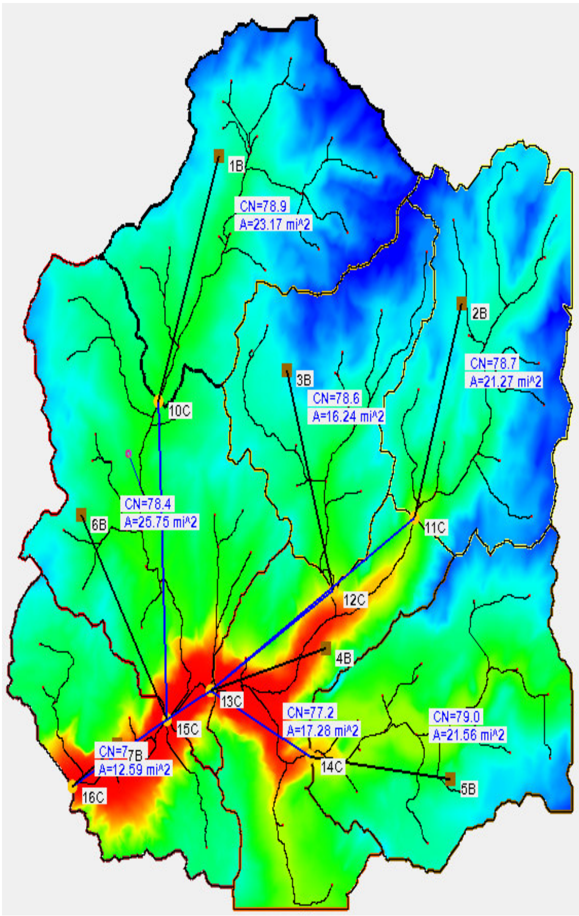

Figure 3: Watershed Delineation View in WMS

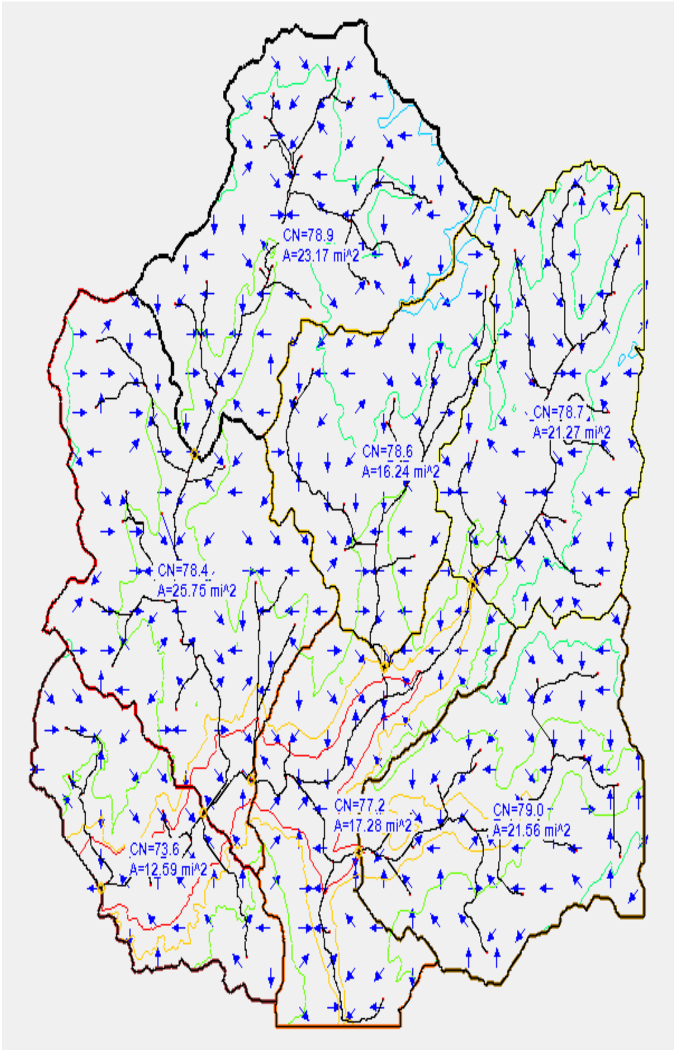

Figure 4: Flow Direction View generated by WMS

Required geometric and hydrologic parameters for HEC-HMS model were calculated in the WMS and saved the output file with as *.hms* extension file. The first scenario was simulated in HEC-HMS without any alteration. which later served as the control scenario for comparison. Scenario-2 was run with 10% less Evergreen Forest Land (group D), which was replaced with Commercial & Services (group D). Similarly, Scenario-3 and Scenario-4 were run with 20% and 30% less Evergreen Forest Land (group D) which were replaced with Commercial & Services (group D), respectively. Total area of sub-basins and the whole watershed was kept unchanged for all four simulation situations. Composite CN of Scenarios 2, 3, and 4 were increased due to the change in land use (Table III).

Table III: Composite CN changes based on Land Use class change at Sub-basin 4B.

Mosammat

Merced County, California

Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
Current	Commercial & business		B	.016	92
	Commercial & business		D	.079	95
	Brush - brush, weed, grass mix	(fair)	D	1.25	77
	Woods	(fair)	B	1.551	60
	Woods	(fair)	D	14.383	79
	Total Area / Weighted Curve Number			17.28	77
10% Incre	Commercial & business		B	.016	92
	Commercial & business		D	1.517	95
	Brush - brush, weed, grass mix	(fair)	D	1.25	77
	Woods	(fair)	B	1.551	60
	Woods	(fair)	D	12.945	79
	Total Area / Weighted Curve Number			17.28	79
20% Incre	Commercial & business		B	.016	92
	Commercial & business		D	2.956	95
	Brush - brush, weed, grass mix	(fair)	D	1.25	77
	Woods	(fair)	B	1.551	60
	Woods	(fair)	D	11.506	79
	Total Area / Weighted Curve Number			17.28	80
30% Incre	Commercial & business		B	.016	92
	Commercial & business		D	4.394	95
	Brush - brush, weed, grass mix	(fair)	D	1.25	77
	Woods	(fair)	B	1.551	60
	Woods	(fair)	D	10.068	79
	Total Area / Weighted Curve Number			17.28	81

5. Results & discussion

Four different scenarios were simulated in the HEC-HMS model. Final outlet 16C, outlet 13C and sub-basin 4B (Figure 5a) were designated for further comparison. Table IV shows the different simulation results at those three designated points. In scenario-1, where the current situation remained unchanged with a weighted curve number of 77, the peak discharge was 73.11 cm^3/s at sub-basin 4B; 271 cm^3/s at Outlet 13C, and 428 cm^3/s at final outlet 16C (Figure 5b). Hydrograph of simualation-1 is shown in Figure 5b. In scenario-2 (with 10% evergreen forestland loss) with a weighted curve number of 79, the peak discharge was 83 cm^3/s at sub-basin 4B; 274 cm^3/s at Outlet 13C and 433 cm^3/s at final outlet 16C. Similar increasing momentum of peak discharge were observed for scenario-3 and scenario-4 where 20% and 30% evergreen forestland loss were occurred, respectively.

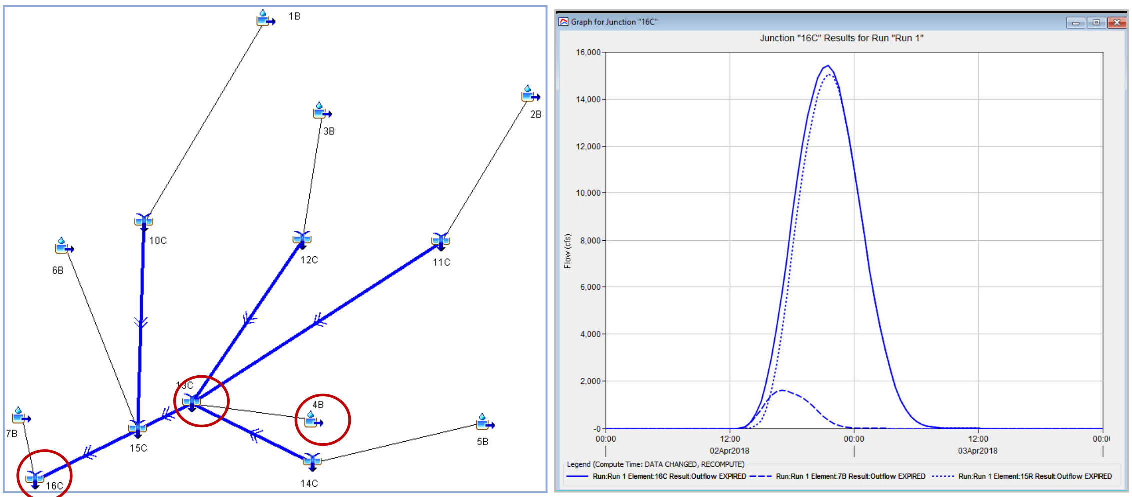

Figure 5: a) HEC-HMS Model Layout b) Hydrograph at final outlet 16C

Table IV: Comparison of Different Simulations

Outlet	Peak Time	Drainage Area (km^2)	Peak Discharge (cm^3/s)	Volume (cm)
Scenario 1				
Sub-basin 4B	02Apr2018, 16:30	44.76	73.11	3.26
Outlet 13C	02Apr2018, 20:00	197.75	270.95	3.45
Final Outlet 16C	02Apr2018, 21:30	357.07	428.39	3.40
Scenario 2				
Sub-basin 4B	02Apr2018, 16:30	44.76	79.25	3.55
Outlet 13C	02Apr2018, 20:00	197.75	272.90	3.52
Final Outlet 16C	02Apr2018, 21:30	357.07	431.66	3.43
Scenario 3				
Sub-basin 4B	02Apr2018, 16:30	44.76	82.80	3.72
Outlet 13C	02Apr2018, 19:30	197.75	274.18	3.55
Final Outlet 16C	02Apr2018, 21:30	357.07	433.50	3.45
Scenario 4				
Sub-basin 4B	02Apr2018, 16:30	44.76	86.38	3.89
Outlet 13C	02Apr2018, 19:30	197.75	275.57	3.59
Final Outlet 16C	02Apr2018, 21:30	357.07	435.34	3.48

Urbanization increases peak discharge as a result, increasing the risk of flooding or flash flooding in any floodplain (Feng *et al.* 2021). This study observed that peak discharge increased in all scenarios due to the change in land-use class and loss of evergreen forest. Nearly 18% peak discharge was increased in scenario 4 at sub-basin 4B (Figure 6). Approximately 2% peak discharge was increased in scenario 1 to 4 at final outlet 16C (Figure 7). The study is consistent with other studies where it was noted that from 2001 to 2011, with an increase of impervious area of 11.21%, the peak discharge was almost doubled (Hu and Shrestha, 2020). Likewise, Poelmans *et al.* 2021 has observed a maximum peak flow increase of 6-16% with 70-200% urban expansion, respectively. Global summary generated by HEC-HMS simulations for all four simulations is shown in Table V.

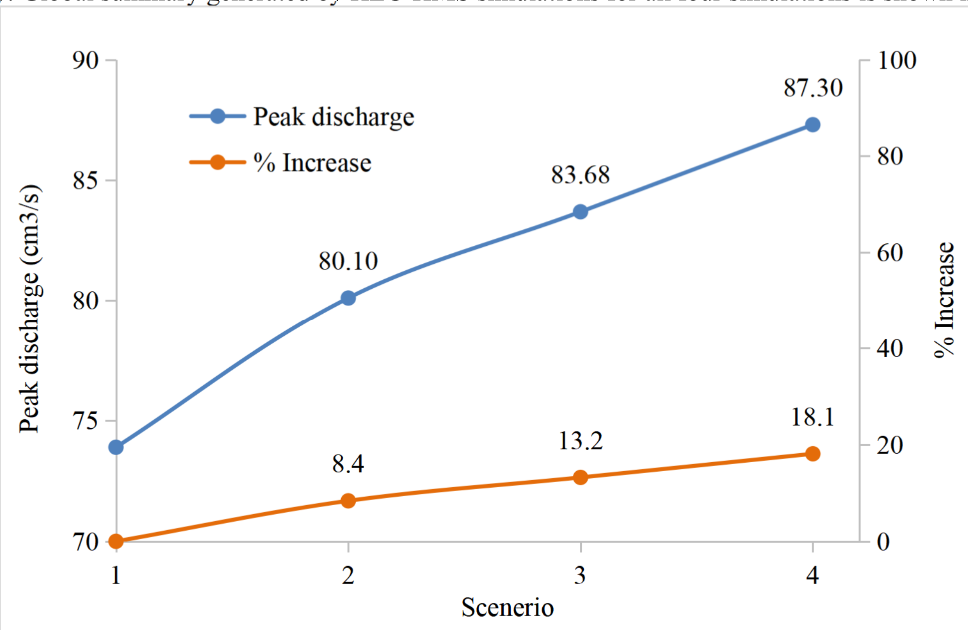

Figure 6: Peak discharge increase in different simulation at sub-basin 4B

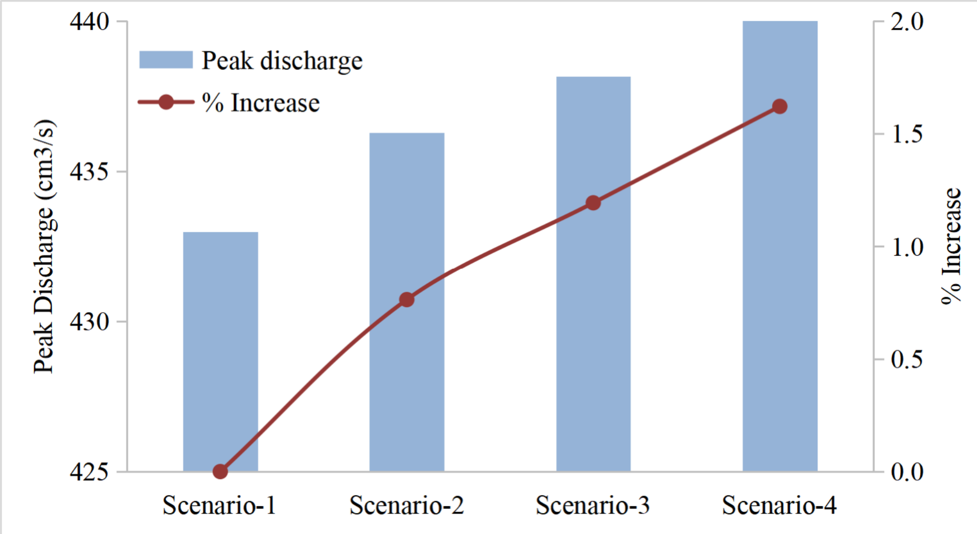

Figure 7: Comparing peak discharge in different simulation at Outlet 16C

Table V: Global summary generated by HEC-HMS simulation for all four simulations

Global Summary Results for Run "Run 1"

Project: wmsexport Simulation Run: Run 1

Start of Run: 02Apr2018, 00:00 Basin Model: WMS Watershed
End of Run: 04Apr2018, 00:00 Meteorologic Model: WMS Meteorologic Data
Compute Time:DATA CHANGED, RECOMPUTE Control Specifications:WMS Control Info

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
5B	21.5608	3380.1094	02Apr2018, 17:00	1.3945
3B	16.2390	2476.8631	02Apr2018, 17:30	1.3684
2B	21.2746	3254.4969	02Apr2018, 17:30	1.3742
4B	17.2788	2611.2312	02Apr2018, 16:30	1.2843
1B	23.1696	3534.2023	02Apr2018, 17:30	1.3918
6B	25.7545	3797.5328	02Apr2018, 17:30	1.3574
7B	12.5899	1609.1849	02Apr2018, 17:00	1.0679
14C	21.5608	3380.1094	02Apr2018, 17:00	1.3945
12C	16.2390	2476.8631	02Apr2018, 17:30	1.3684
11C	21.2746	3254.4969	02Apr2018, 17:30	1.3742
13C	76.3532	9676.8744	02Apr2018, 20:00	1.3583
10C	23.1696	3534.2023	02Apr2018, 17:30	1.3918
15C	125.2773	14964.3858	02Apr2018, 20:30	1.3643
16C	137.8672	15299.7720	02Apr2018, 21:30	1.3373
14R	21.5608	3373.9079	02Apr2018, 19:00	1.3945
12R	16.2390	2464.9670	02Apr2018, 19:30	1.3684
11R	21.2746	3254.4969	02Apr2018, 21:30	1.3742
13R	76.3532	9656.7785	02Apr2018, 21:00	1.3583
10R	23.1696	3506.4284	02Apr2018, 19:00	1.3918
15R	125.2773	14950.4507	02Apr2018, 21:30	1.3643

a) Scenario-1: Current situation without loss of evergreen land

Global Summary Results for Run "Run 1"

Project: wmsexport Simulation Run: Run 1

Start of Run: 02Apr2018, 00:00 Basin Model: WMS Watershed
End of Run: 04Apr2018, 00:00 Meteorologic Model: WMS Meteorologic Data
Compute Time:27Apr2019, 11:59:19 Control Specifications:WMS Control Info

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
5B	21.5608	3380.1094	02Apr2018, 17:00	1.3945
3B	16.2390	2476.8631	02Apr2018, 17:30	1.3684
2B	21.2746	3254.4969	02Apr2018, 17:30	1.3742
4B	17.2788	2830.4087	02Apr2018, 16:30	1.3971
1B	23.1696	3534.2023	02Apr2018, 17:30	1.3918
6B	25.7545	3797.5328	02Apr2018, 17:30	1.3574
7B	12.5899	1609.1849	02Apr2018, 17:00	1.0679
14C	21.5608	3380.1094	02Apr2018, 17:00	1.3945
12C	16.2390	2476.8631	02Apr2018, 17:30	1.3684
11C	21.2746	3254.4969	02Apr2018, 17:30	1.3742
13C	76.3532	9746.5563	02Apr2018, 20:00	1.3839
10C	23.1696	3534.2023	02Apr2018, 17:30	1.3918
15C	125.2773	15068.6603	02Apr2018, 20:30	1.3799
16C	137.8672	15416.4230	02Apr2018, 21:30	1.3514
14R	21.5608	3373.9079	02Apr2018, 19:00	1.3945
12R	16.2390	2464.9670	02Apr2018, 19:30	1.3684
11R	21.2746	3254.4969	02Apr2018, 21:30	1.3742
13R	76.3532	9742.7226	02Apr2018, 21:00	1.3839
10R	23.1696	3506.4284	02Apr2018, 19:00	1.3918
15R	125.2773	15067.1017	02Apr2018, 21:30	1.3799

b) Scenario-2: 10% loss of evergreen land

Global Summary Results for Run "Run 1"

Project: wmsexport Simulation Run: Run 1

Start of Run: 02Apr2018, 00:00 Basin Model: WMS Watershed
End of Run: 04Apr2018, 00:00 Meteorologic Model: WMS Meteorologic Data
Compute Time:27Apr2019, 12:22:28 Control Specifications:WMS Control Info

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
5B	21.5608	3380.1094	02Apr2018, 17:00	1.3945
3B	16.2390	2476.8631	02Apr2018, 17:30	1.3684
2B	21.2746	3254.4969	02Apr2018, 17:30	1.3742
4B	17.2788	2956.9729	02Apr2018, 16:30	1.4637
1B	23.1696	3534.2023	02Apr2018, 17:30	1.3918
6B	25.7545	3797.5328	02Apr2018, 17:30	1.3574
7B	12.5899	1609.1849	02Apr2018, 17:00	1.0679
14C	21.5608	3380.1094	02Apr2018, 17:00	1.3945
12C	16.2390	2476.8631	02Apr2018, 17:30	1.3684
11C	21.2746	3254.4969	02Apr2018, 17:30	1.3742
13C	76.3532	9792.0801	02Apr2018, 19:30	1.3989
10C	23.1696	3534.2023	02Apr2018, 17:30	1.3918
15C	125.2773	15135.7518	02Apr2018, 20:00	1.3891
16C	137.8672	15482.2890	02Apr2018, 21:30	1.3598
14R	21.5608	3373.9079	02Apr2018, 19:00	1.3945
12R	16.2390	2464.9670	02Apr2018, 19:30	1.3684
11R	21.2746	3254.4969	02Apr2018, 21:30	1.3742
13R	76.3532	9791.0053	02Apr2018, 21:00	1.3989
10R	23.1696	3506.4284	02Apr2018, 19:00	1.3918
15R	125.2773	15132.9677	02Apr2018, 21:30	1.3891

c) Scenario-3: 20% loss of evergreen land

Global Summary Results for Run "Run 1"

Project: wmsexport Simulation Run: Run 1

Start of Run: 02Apr2018, 00:00 Basin Model: WMS Watershed
End of Run: 04Apr2018, 00:00 Meteorologic Model: WMS Meteorologic Data
Compute Time:27Apr2019, 12:27:13 Control Specifications:WMS Control Info

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
5B	21.5608	3380.1094	02Apr2018, 17:00	1.3945
3B	16.2390	2476.8631	02Apr2018, 17:30	1.3684
2B	21.2746	3254.4969	02Apr2018, 17:30	1.3742
4B	17.2788	3084.8428	02Apr2018, 16:30	1.5322
1B	23.1696	3534.2023	02Apr2018, 17:30	1.3918
6B	25.7545	3797.5328	02Apr2018, 17:30	1.3574
7B	12.5899	1609.1849	02Apr2018, 17:00	1.0679
14C	21.5608	3380.1094	02Apr2018, 17:00	1.3945
12C	16.2390	2476.8631	02Apr2018, 17:30	1.3684
11C	21.2746	3254.4969	02Apr2018, 17:30	1.3742
13C	76.3532	9841.6940	02Apr2018, 19:30	1.4145
10C	23.1696	3534.2023	02Apr2018, 17:30	1.3918
15C	125.2773	15204.7744	02Apr2018, 20:00	1.3985
16C	137.8672	15547.7197	02Apr2018, 21:30	1.3683
14R	21.5608	3373.9079	02Apr2018, 19:00	1.3945
12R	16.2390	2464.9670	02Apr2018, 19:30	1.3684
11R	21.2746	3254.4969	02Apr2018, 21:30	1.3742
13R	76.3532	9838.7861	02Apr2018, 21:00	1.4145
10R	23.1696	3506.4284	02Apr2018, 19:00	1.3918
15R	125.2773	15198.3984	02Apr2018, 21:30	1.3985

d) Scenario-4: 30% loss of evergreen land

6. Discussion

Simulation results indicate that urbanization negatively impacts peak discharges in watersheds. Urbanization in a sub-basin has a direct effect on the CN number, which ultimately increase the discharge rate from a sub-basin and subsequently increases the discharge at the main outlet of a watershed. Observations have shown that destruction of evergreen forests in any sub-basin increases the drainage rate of a watershed.

7. Conclusion

The study found that discharge volumes were increased in all scenarios due to land-use class changes. Nearly 18% increase has been noticed on peak discharge from scenario 1 to 4 at sub-basin level. About 2% increase has been noticed on peak discharge from scenario 1 to 4 both at the final outlet. Such land use changes increase the likelihood of flooding in areas that are undergoing rapid urbanization. Furthermore, the study revealed that sub-basin curve numbers were affected by land use changes, which was the underlying cause of flow increases from a watershed. With increasing urbanization, the curve numbers were increasing and as a result, total maximum discharges were also increased. In brief, the study found direct evidence of an increase in peak discharge of watersheds with the increasing trend of urbanization. This should be kept in mind when deciding on future strategic planning, urban planning, policy formulation and flood control programs.

8. Future research scope

Watershed models are also useful tools for analyzing water quality. The limitation of this study was it did not consider water quality aspect at this time. Since the study revealed the interrelationship between land use class change / urbanization and maximum discharge, it is certain that water quality will also be affected by urbanization. There is potential scope for future researcher to work on this aspect.

References

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