

Identifying areas sensitive to land use/land cover change for downstream flooding in a coastal Alabama watershed

Navideh Noori¹ · Latif Kalin² · Sumit Sen³ · Puneet Srivastava⁴ · Charlene Lebleu⁵

Received: 14 October 2014 / Accepted: 17 January 2016 / Published online: 11 February 2016
© Springer-Verlag Berlin Heidelberg 2016

Abstract This paper explored the linkage between historic, current and future land use/land cover (LULC) conditions and peak flow and runoff volumes in a coastal community in Alabama in an effort to identify critical areas for downstream flooding. The study demonstrated that critical areas cannot be determined intuitively without conducting modeling studies. The study watershed, Eight-mile Creek, experienced approximately 48 % forest loss between 1966 and 2011 largely due to urbanization. Residential development is expected to continue mostly in the central part of the watershed in the near future. Historic,

current and future LULC maps were developed by processing aerial imagery, which were used in the HEC-HMS hydrologic model to study flood risk. An index method was applied to estimate the contribution of different parts of the watershed to downstream peak flows. The model showed a significant increase in peak flow and runoff volume from 1966 to 2011 and from 2011 to 2022 due to urbanization. The sensitivity of peak flows to LULC change decreased with increasing storm return periods, but the order of importance of different parts of the watershed, in terms of flooding, did not change significantly. Results of this study demonstrate the need for sustainable development by targeting areas that can have the least impacts on downstream flooding. The methodology presented in this paper can help decision makers propose land use alternatives to minimize adverse environmental impacts.

Editor: Xiangzheng Deng.

✉ Latif Kalin
latif@auburn.edu

Navideh Noori
nnoori@uga.edu

Sumit Sen
ssenhfhy@iitr.ac.in

Puneet Srivastava
srivapu@auburn.edu

Charlene Lebleu
leblecm@auburn.edu

- ¹ Odum School of Ecology, University of Georgia, 140 E Green St, Athens, GA 30602, USA
- ² School of Forestry and Wildlife Sciences, Auburn University, 602 Duncan Drive, Auburn, AL 36849-5126, USA
- ³ Department of Hydrology, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India
- ⁴ Biosystems Engineering Department, Auburn University, 206 Tom E. Corley Building, Auburn, AL 36849, USA
- ⁵ School of Architecture, Planning and Landscape Architecture, Auburn University, 104 Dudley Hall, Auburn, AL 36849, USA

Keywords Land use · Land cover · Urbanization · Flooding · HEC-HMS

Introduction

The population of coastline counties in the USA has grown steadily in recent decades, with a 39 percent increase (34.8 million people) from 1970 to 2010. By 2020, US coastal population density is projected to increase by 37 persons per square mile, as compared to an increase in 11 persons per square mile for the USA as a whole (U.S. Census Bureau 2011; Woods and Poole Economics, Inc. 2011). Due to increases in human population and economic development, rate of deforestation, urbanization and other types of land use/land cover (LULC) changes have accelerated. Land use changes and land cover disturbances can affect hydrological processes by modifying evapotranspiration rates, flood peaks, sediment

transport rates, concentration of water quality constituents and many other processes (Eshleman 2004). Impact of LULC change on peak flow and runoff volume are observed mostly at low intensity and frequent rainfall events, because small flooding events are more sensitive to urbanization than large flooding events (Saghafian et al. 2008; Chen et al. 2009; Amini et al. 2011, Olang and Furst 2011, Du et al. 2012). During very intense, infrequent events, precipitation rates can substantially overwhelm infiltration capacity and soil surfaces begin to behave similar to impervious surfaces. However, it is noted that extreme events may still experience increased flows in urbanizing watersheds due to greater hydraulic efficiency (Smith et al. 2002). Reduction in evapotranspiration due to urbanization during the growing season can elevate peak flow rates and annual discharge volumes (Boggs and Sun 2011). The effect of LULC changes on peak discharge and runoff volume will be severe in areas with high rates of deforestation and agricultural expansion (Olang and Furst 2011).

Assessment of how LULC changes over time and how these changes affect streamflow can be achieved through field observations or simulation modeling. Field studies are expensive and very time-consuming. Results are also generally local and nontransferable. Thus, watershed models are commonly utilized to assess or predict the effect of urbanization and, in general, LULC changes on streamflow. The effect of urbanization on hydrological responses of watersheds have been well studied (Birkinshaw et al. 2011; Taubenbock et al. 2011; Dixon and Earls 2012; Du et al. 2012; Qaiser et al. 2012; Verbeiren et al. 2013). These studies, in general, show that forest-to-urban conversion, especially in upstream areas, increases peak discharge and runoff volume in downstream locations. Increasing urbanization, in terms of both area and intensity, could lead to higher water elevations during flood events, and as a consequence, flood inundation can extend into much larger areas. Further, the sensitivity of hydrologic response to urbanization decreases as the return period of rainfall events increases (Verbeiren et al. 2013).

Although the literature is replete with modeling studies scrutinizing the changes in streamflow under varying LULC conditions (Olang and Furst 2011; Taubenbock et al. 2011; Dixon and Earls 2012; Qaiser et al. 2012; Ty et al. 2012), fewer studies looked at the effect of LULC spatial configuration (specifically imperviousness) on the streamflow pattern (Mejia and Moglen 2009, Zhang and Shuster 2014). Almost no study exists focusing on identifying areas that would be least preferable for the development in the future when their impacts on downstream flooding are concerned. The emphasis in most past studies has been how peak flow and/or surface runoff volume respond to urbanization. The spatial pattern of urbanization in conjunction with its intensity can play a crucial role in downstream hydrological fluxes. Studies on this topic explored this problem either

qualitatively or at a course scale (Zhou et al. 2013). Same level of urban development (or imperviousness) in different parts of a watershed could have varying levels of contributions to streamflow volume and peak at downstream locations due to differences in topography, soil characteristics and location within the watershed. Estimating spatial pattern of potential flood generating areas in a watershed would be more beneficial than only providing the flood inundation maps for urban planners. Decision makers can concentrate their efforts and resources in those areas to minimize the negative impacts of future development on environment (Verbeiren et al. 2013).

This study validated and applied an index-based method developed by Kalin and Hantush (2009) to a coastal watershed near the city of Mobile in southwest Alabama, to probe potential impacts of urbanization on flooding as well as to identify key areas in the study watershed that can have higher contribution to downstream flooding if developed. This method was applied to a mountainous watershed in the previous study. The flat terrain of the study area has been sensitive to flooding because of the abundance of rainfall. Also, because of ongoing urban development, flood risk will continue to be a major concern in the near future. It was hypothesized that the most sensitive areas to downstream flooding are not near the outlet and even urbanization in the most upstream part of the watershed can play an important role in downstream hydrological fluxes. To define this hypothesis, three LULC conditions were considered in the watershed: 1966 (historic), 2011 (current) and 2022 (future). Future LULC was generated by working closely with the local planning commission. The effects of historical and potential future LULC changes on streamflow were assessed for 1-, 10-, 25- and 100-year return period storms, and sensitive areas within the watershed were identified based on their contribution to downstream flooding. Results of this study showed that distributed watershed models are needed in order to better identify the most critical areas in terms of downstream flooding. This provided input to municipal subdivision regulations within the study area to help them make science-based decisions in their future development plans.

Study area

The Eightmile Creek (EMC) watershed is located in southwest Alabama near the city of Mobile (Fig. 1). Eightmile Creek joins the Chickasaw Creek at its confluence with Mobile River flowing into the Gulf of Mexico. A significant portion of this watershed is located within the city limits of Mobile, Prichard and Chickasaw. The study area has a mild subtropical climate with hot and humid summers and mild and rainy winters. The long-term

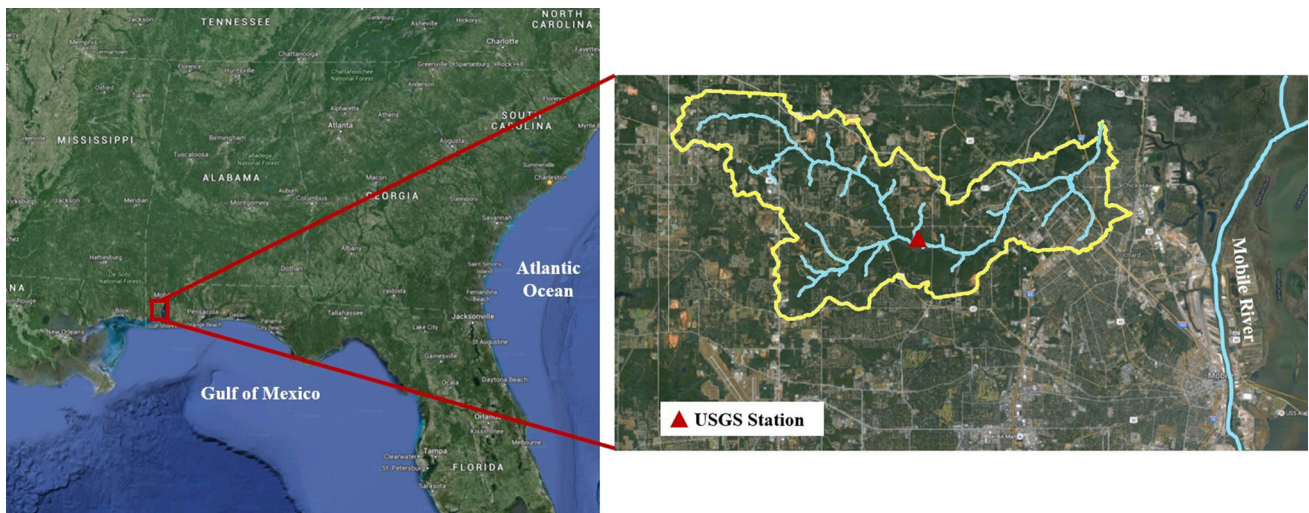


Fig. 1 Eightmile Creek watershed in southeast Mobile County, AL

average annual precipitation and mean temperature are 1578 mm and 19.6 °C, respectively (NOAA National Climate Data Center). Soil in this watershed is uniformly distributed and is mostly sandy soil with moderate permeability. The watershed has an area of 89.1 km² with the elevation ranging from ~0 to 24 m above mean sea level (MSL). The area is no stranger to frequent extreme events, especially hurricanes. For instance, Hurricane Danny was directed northeast through the Gulf of Mexico and Mobile Bay on July 19, 1997, and dropped 330 mm of rain to the EMC watershed.

Dominant LULC types in 2011 in the study area were 45 % forest, 29 % developed area including residential and commercial areas and 11 % wetland and riparian areas (Fig. 2). Most of the eastern part of the study area is already developed and according to the city of Prichard, approximately 15-km² (17 %) additional residential area with medium intensity in the central and western part of the watershed is expected by 2022. When combined with abundant rainfall, the flood risk will be a major concern in the near future in this area. Understanding increased risk and severity of downstream flooding as a consequence of future developments in this watershed would help planners allocate land for the development and/or preservation.

Methodology

Historic, current and future LULC

To evaluate LULC changes over time and to see how locations of these changes affect flow characteristics, historic, current and future LULC conditions were considered for the EMC watershed. The aerial photographs of the

study area corresponding to 1966 were acquired from the Auburn University Library (1.75 m × 1.75 m), and aerial photographs of 2011 were obtained from the National Agriculture Imagery Program (1.0 m × 1.0m). Applying the *eCognition* image analysis software 8.0 (Definiens 2009), the aerial photographs were classified based on Anderson Level I classification (Anderson et al. 1976). Object-oriented image analysis (OBIA) was carried out by developing set of rules to hierarchically classify image segments. OBIA approaches image analysis by combining spectral information as well as spatial information such as texture and contextual information in the image (Flanders et al. 2003). After creating 12 major categories of land cover at the modified Anderson Level I scheme, classification samples were selected for each category. Based on the samples collected, a nearest neighbor algorithm was applied. Finally, the classified image objects were merged into respective classes, and then, the merged classes were exported in a vector format as an output to produce the land cover maps. The ancillary data, such as land use map from the city of Prichard, were also used for developing 2011 land cover map and a future projection map. The kappa statistics calculated for 1966 and 2011 are 0.797 and 0.822, respectively. The overall accuracy of generated maps for year 1966 and 2011 is 81.9 and 84.0 %, respectively. The strength of agreement is considered to be good and very good for the year 1966 and 2011, respectively. Figure 2 shows LULC for years 1966 and 2011.

In 2012, we worked closely with the city of Prichard to predict and overlay future development of the watershed for the next 10 years onto the 2011 LULC map in ArcGIS 10.0 (ESRI 2010) to develop the 2022 LULC map. The predicted LULC map suggests continuing increase in medium intensity residential area by 17 % during

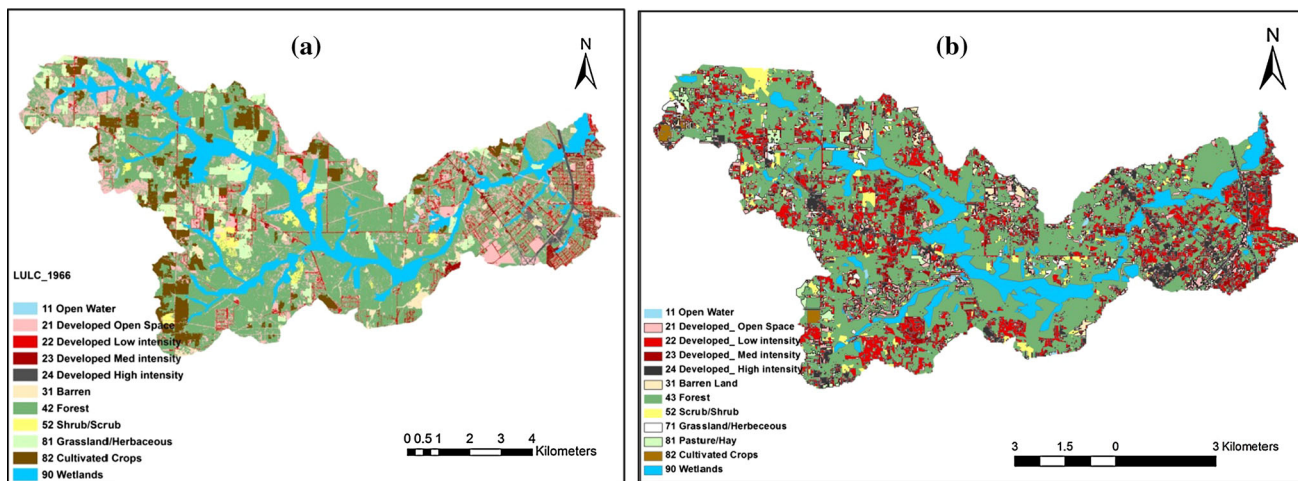


Fig. 2 LULC map of the EMC watershed in **a** 1966 and **b** 2011. The land use types were classified based on Anderson Level I classification

2011–2022. This confirms that urbanization is one of the most important driving forces resulting in the general trends in land use change in the future.

Changes in LULC from 1966 to 2011 and from 2011 to 2022 are presented in Table 1 and Fig. 3. Main LULC change is the conversion of forest to open space and residential areas with 48 and 21 % forest loss from 1966 to 2011 and from 2011 to 2022, respectively. Eight sensitive or potential flood generating areas based on LULC changes from 1966 to 2011 and eleven sensitive areas based on the expected LULC changes from 2011 to 2022 were considered (Fig. 3a, b).

HEC-HMS model

The Hydrologic Engineering Center–Hydrologic Modeling Systems (HEC-HMS), a watershed-scale hydrologic model, was applied in this study to explore the impacts of LULC changes on peak flow and runoff volume in the EMC watershed. HEC-HMS has extensively been used in assessing the effects of LULC changes (predominantly urbanization) on hydrologic processes (Wan and Yang 2007; Lin et al. 2009; Chen et al. 2009; Verma et al. 2010; Ali et al. 2011; Amini et al. 2011, Du et al. 2012).

To calculate streamflow using the HEC-HMS model, the kinematic wave transform method was used to compute direct surface runoff hydrographs, and the exponential recession method was used for baseflow calculation. Runoff volumes were computed using the Soil Conservation Service Curve Number (SCS-CN) method. The SCS-CN method has been in existence for about 50 years and is a popular means of estimating storm runoff from rainfall events (Hawkins et al. 2009). It estimates the rainfall excess as a function of cumulative rainfall, land use, vegetation and antecedent soil moisture condition. The SCS-CN runoff equation is

$$Q = \frac{(P + I_a)^2}{(P - I_a + S)} \quad \text{if } P \geq I_a, \quad \text{else } Q = 0 \tag{1}$$

$$I_a = \lambda S \tag{2}$$

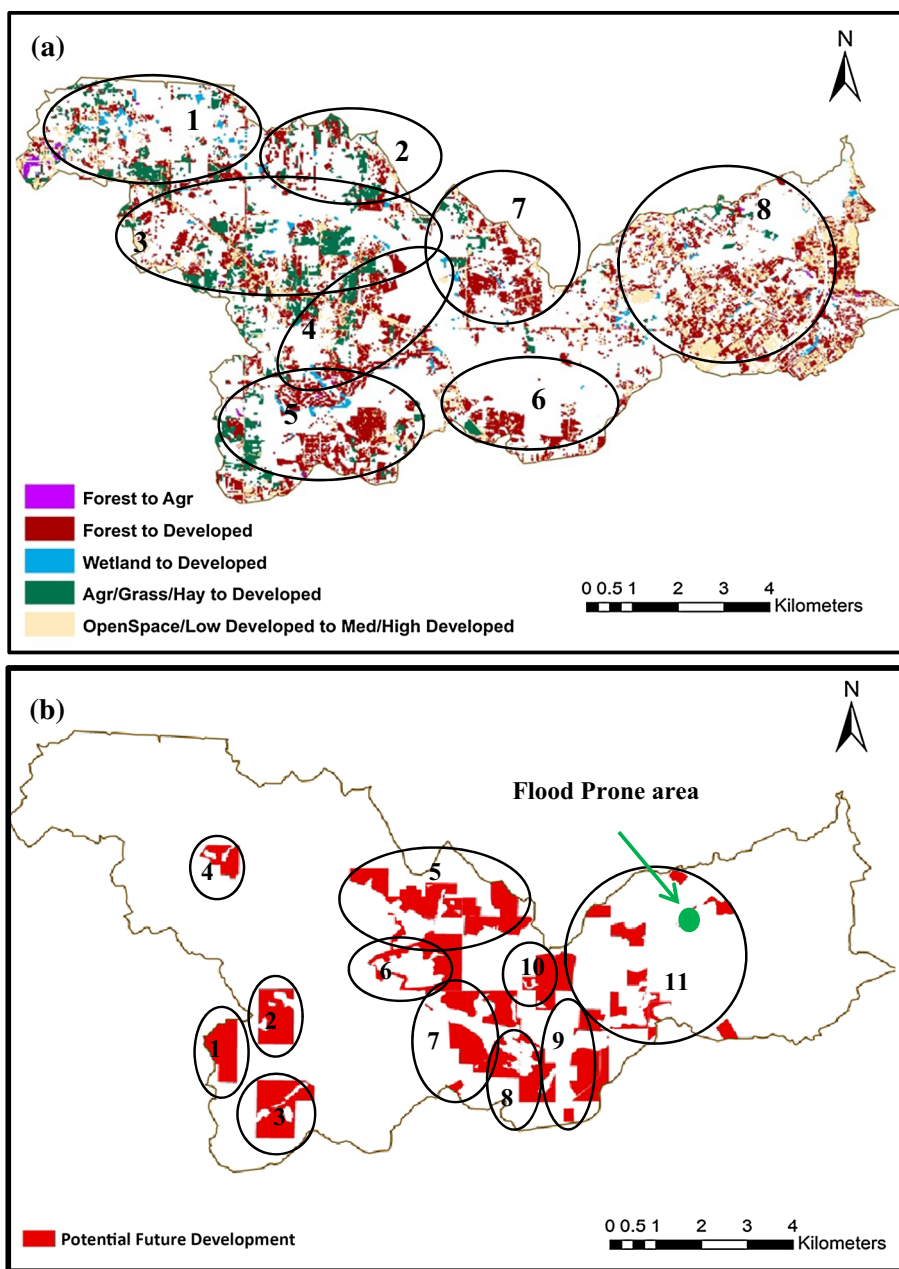
$$S = \frac{25,400}{CN} - 254 \quad 0 < CN < 100 \tag{3}$$

where Q = direct runoff (mm), P = total rainfall depth (mm), S = potential maximum retention (mm), I_a = initial abstraction (mm), λ = initial abstraction ratio and CN = curve number. The empirical value of λ suggested

Table 1 LULC changes from 1966 to 2011 and from 2011 to 2022 for the EMC watershed (Fig. 1)

	1966–2011 (%)	2011–2022 (%)
Forest to developed	15.7	9.3
Agriculture/grass/hay to developed	4.7	0.6
Wetland to developed	0.9	0.2
Open space/low developed to medium/high developed	4.2	0.8
Open space to low/medium/high developed	5.8	0.3
Forest to agriculture/grass	0.2	–
Forest loss	48.4	20.9

Fig. 3 LULC change maps: **a** 1966–2011 (main LULC conversion from 1966 to 2011), **b** 2011–2022 (potential future development locations). *Black circles* show the potential flood generating areas; *green circle* shows the flood-prone area (color figure online)



by SCS (1972) is 0.2. However, the validity of this assumption has been questioned in many studies (Jiang 2001; Woodward et al. 2003; Mishra and Singh 2004; Baltas et al. 2007; Shi et al. 2009; Fu et al. 2011; Gao et al. 2012). For event rainfall–runoff data, λ value varies from storm to storm and from watershed to watershed. Jiang (2001) used both event-based and model fitting methods from 307 watersheds in the USA to evaluate λ and found that most of the λ values were less than 0.2 and a rounded value of 0.05 was more appropriate than $\lambda = 0.2$ for runoff calculations. When $\lambda = 0.05$, the CN values should be updated according to the following formula (Jiang 2001)

$$CN_{0.05} = \frac{100}{1.879 \left[\frac{100}{CN_{0.20}} - 1 \right]^{1.15} + 1} \tag{4}$$

Before studying the LULC impacts on the streamflow in the EMC watershed, the model performance was tested using 4 years of streamflow data (1996–2000) provided by the US Geological Survey (USGS). Figure 1 shows the location of the USGS gage. The model was run using hourly precipitation data from the NCDC Mobile Regional Airport station and the 2001 National Land Cover Database (NLCD). Generated peak flows and runoff volumes from several selected big events were assessed qualitatively

through graphs and quantitatively through the coefficient of determination (R^2), Nash–Sutcliffe efficiency (E_{NASH}) and bias ratio (R_{BIAS}) (Moriassi et al. 2007). The model was also run with both λ values to see whether $\lambda = 0.05$ indeed provides superior results.

Once the model was tested, effects of different LULC conditions on peak flows and runoff volumes were evaluated. The model was run with design storms having return periods of 1, 10, 25 and 100 years to generate peak flows at a site identified as flood-prone area (Fig. 3b). This site was chosen based on the observations and after discussions with the city of Prichard planning division. The effect of LULC changes can be assessed in other parts of the watershed in a similar manner. Table 2 shows the storm depth for different return periods obtained from the Alabama Rainfall Atlas (<http://bama.ua.edu/~rain>). NOAA Atlas 14 was not available for the study area when the study was conducted.

Index method

To identify the areas in the EMC watershed potentially playing critical roles in downstream flooding, the index method developed by Kalin and Hantush (2009) was validated and applied. Two LULC change periods were considered: (1) from 1966 to 2011 and (2) from 2011 to 2022. First, the HEC-HMS model was run using the 2011 LULC for various design storms to estimate the peak flows (Q) at the identified downstream site. Next, it was assumed that all the sub-watersheds have the 2011 LULC with the exception of sub-watershed j retaining its past status, i.e., 1996 LULC. The model generated peak flow at the downstream site with this LULC setup was denoted as Q_j . The following metrics are defined to assess the potential relative impact of element j on the peak flow:

$$\Omega_j = \left(\frac{Q_j}{Q} - 1 \right) \times 100 \quad (5)$$

$$\psi_j = \frac{\Omega_j}{A_j/A} \quad (6)$$

where A_j is the area of element j and A is the area of the watershed draining to the downstream site. In Ω , impact of LULC changes on peak flow is captured without

considering the area impact. The ψ -index, on the other hand, is suitable for assessing the impact of LULC changes per unit area. By computing ψ_j for $j = 1, \dots, m$, the sensitive areas in the watershed can be ranked from most critical to least critical. This can provide valuable information to decision makers and urban planners in that they can focus on those areas in the watershed having the highest contribution to the downstream flooding.

The same procedure was repeated for the transition of LULC from 2011 to 2022. In this case, it was assumed that all the sub-watersheds have the 2022 LULC with the exception of sub-watershed j retaining its past status (i.e., LULC of 2011). The model was run under this LULC setup, and peak flows were generated at the downstream site to calculate the Ω and ψ indexes.

Results and discussion

HEC-HMS validation

Figure 4 compares generated streamflow hydrographs by HEC-HMS using λ values of 0.05 and 0.2 to observed hydrographs for some selected large events from the period 1996–2000. Large events were purposely selected, because the focus of this study is on flooding. As shown in Fig. 4, the simulated hydrographs closely match the observed streamflow hydrographs when $\lambda = 0.05$. Taking Moriassi et al. (2007) as base (although they suggested the model rating performance for monthly time step), observed streamflow and generated streamflow using $\lambda = 0.05$ for 12 storm events were compared. For peak flows, E_{NASH} , R^2 and R_{BIAS} values were 0.97, 0.98 and 13 %, respectively, which is considered “good” to “very good” according to Moriassi et al. (2007). For runoff volumes, E_{NASH} , R^2 and R_{BIAS} values were 0.71, 0.94 and -7 %, respectively, and the model performance was again “good” to “very good.” Figure 5 shows scatter plots of simulated peak flows and runoff volumes versus observed counterparts for both λ values. Note that none of the default model parameters were fine-tuned or calibrated in reaching to these results.

Table 2 24-h storm characteristics

Return period (year)	Rainfall depth (cm)	Maximum intensity (cm/h)
1	9.4	2.4
10	16.8	4.2
25	19.3	4.9
100	27.3	6.9

Note that the time of concentration of the EMC watershed is about 18 h. Thus, 24-h duration storms were selected

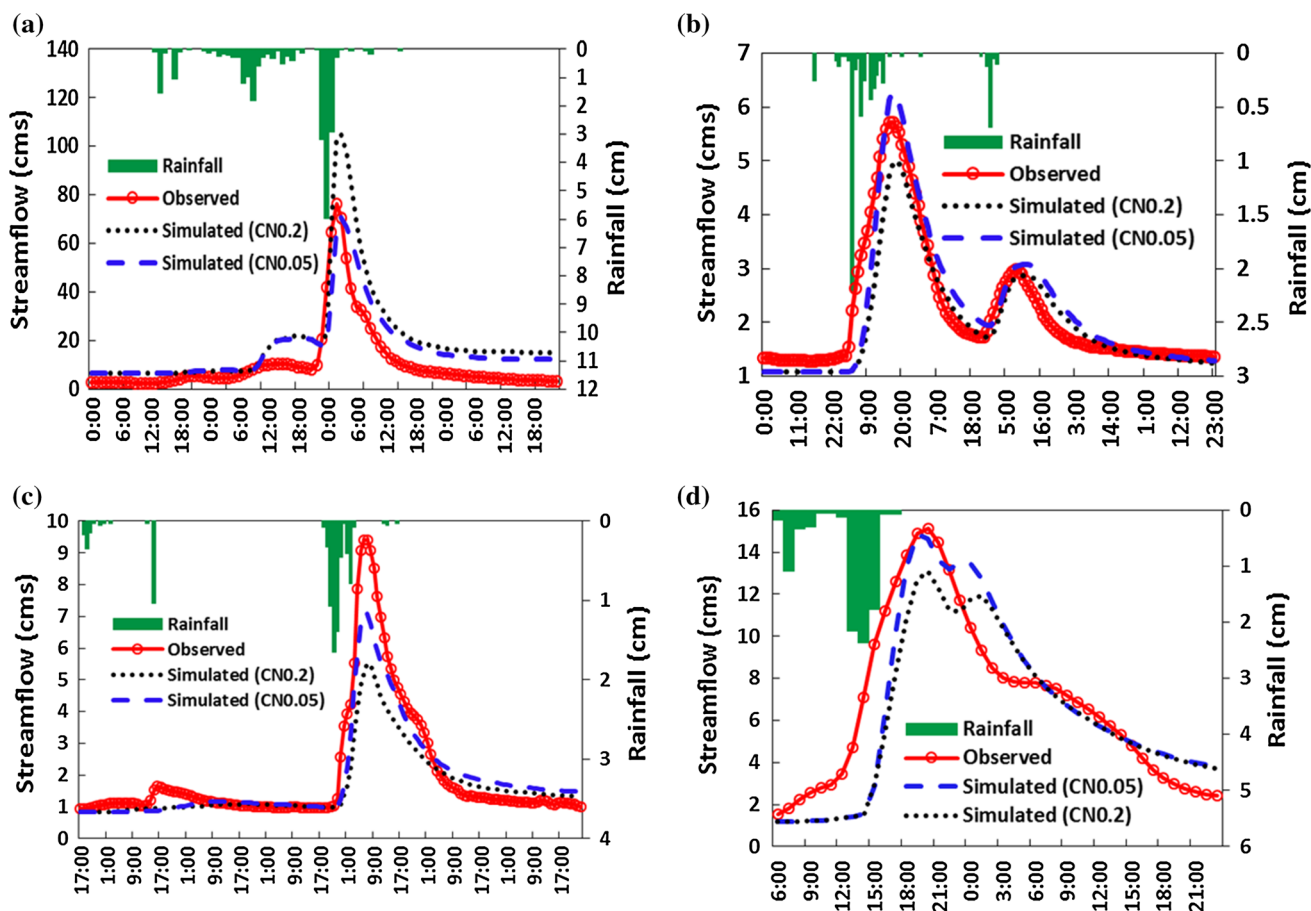


Fig. 4 Observed and HEC-HMS generated flow hydrographs with $\lambda = 0.2$ and $\lambda = 0.05$ for some selected events: a March 7, 1998; b January 7, 1997; c March 18, 2000; and d March 13, 1997

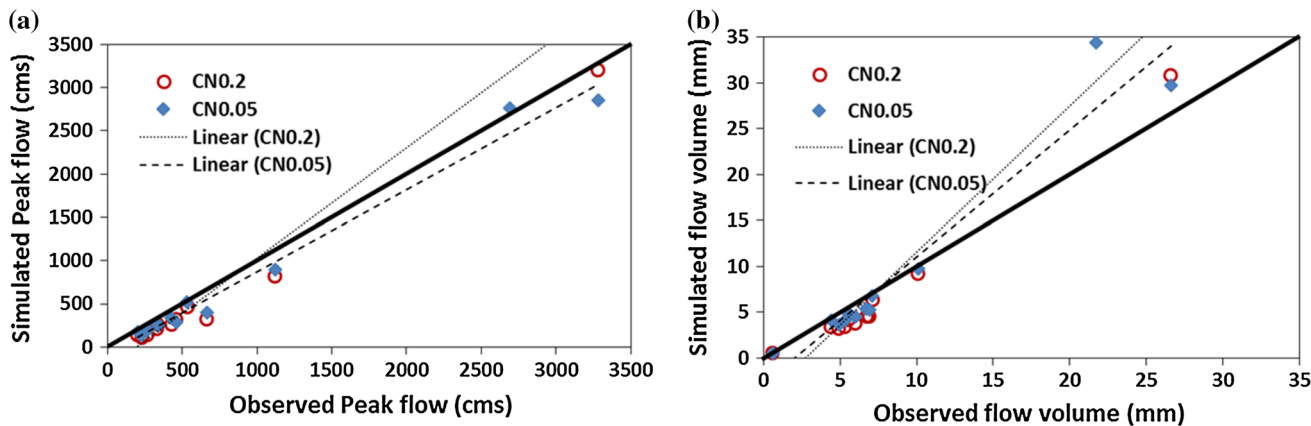


Fig. 5 Comparison of simulated and observed a peak flows and b runoff volumes

Peak flow and runoff volume response to LULC change

HEC-HMS was run under each of the three LULC conditions and with design storms having return periods of 1, 10, 25 and 100 years. Peak flows and runoff volumes at the

flood-prone area are shown in Fig. 6. LULC changes have a larger impact on peak flows than on runoff volumes. The 1-year return period peak flow generated under LULC 2022 and the 10-, 25- and 100-year return period peak flows generated under both LULC 2011 and 2022 are all larger than the critical flow for the bankfull stage ($\sim 40 \text{ m}^3/\text{s}$).

This indicates how urban development in this watershed can cause the stream overflow its banks and flood the nearby areas. Conversion of forested land to urban areas led to significant increase in peak flow and runoff volume, both from 1966 to 2011 and from 2011 to 2022. This is more noticeable for small storms. The relative impacts of urbanization on peak flow and runoff volume decrease with increased storm return period. This finding agrees with previous studies that flood magnitude of rare events is less sensitive to increases in percent imperviousness than those with shorter return periods in a watershed (Du et al. 2012).

Flood indexes

1966–2011

The Ω and ψ indexes were calculated for the eight selected sensitive areas (see Fig. 3a) to assess the impacts of LULC changes from 1966 to 2011 on peak flow and to rank the sensitive areas based on their contribution to downstream flooding. According to Fig. 7a, the top three areas in terms

of their impact on peak flows at the selected site, in order, were 3, 5 and 4. If the LULC of Area 3 had remained in its 1966 conditions, then the peak flows would have been 14–19 % smaller depending on the return period of the storm. Similarly, if the LULC of Area 5 had remained in its 1966 conditions, then the peak flows would have been 12–15 % smaller depending on the return period of the storm. In case of Area 4, the corresponding reduction would have been 10–13 %. Note that none of these three areas (i.e., 3, 4, 5) have the largest area (Table 3). On average, imperviousness in these three areas increased about 15.3 % from 1966 to 2011 and mostly was due to conversion of forest (5.7 %), wetland (5.3 %) and pasture/hay (3.3 %) (Table 3). Areas 1 and 8 are the largest in terms of area. Interestingly, although Area 3 had the largest impact, the increase in CN in Area 3 (+9) was not larger than the increase in CN of any other areas (varied from +9 to +17, Table 3). These indicate the complex interaction between various factors, such as topography, soil, LULC and topology that collectively derive hydrology. Effects of urbanization on hydrologic responses depend on the spatial

Fig. 6 Changes in runoff volumes and peak flows at the flood-prone site in response to LULC changes for different return period design storms: **a** peak flow and **b** flow volume

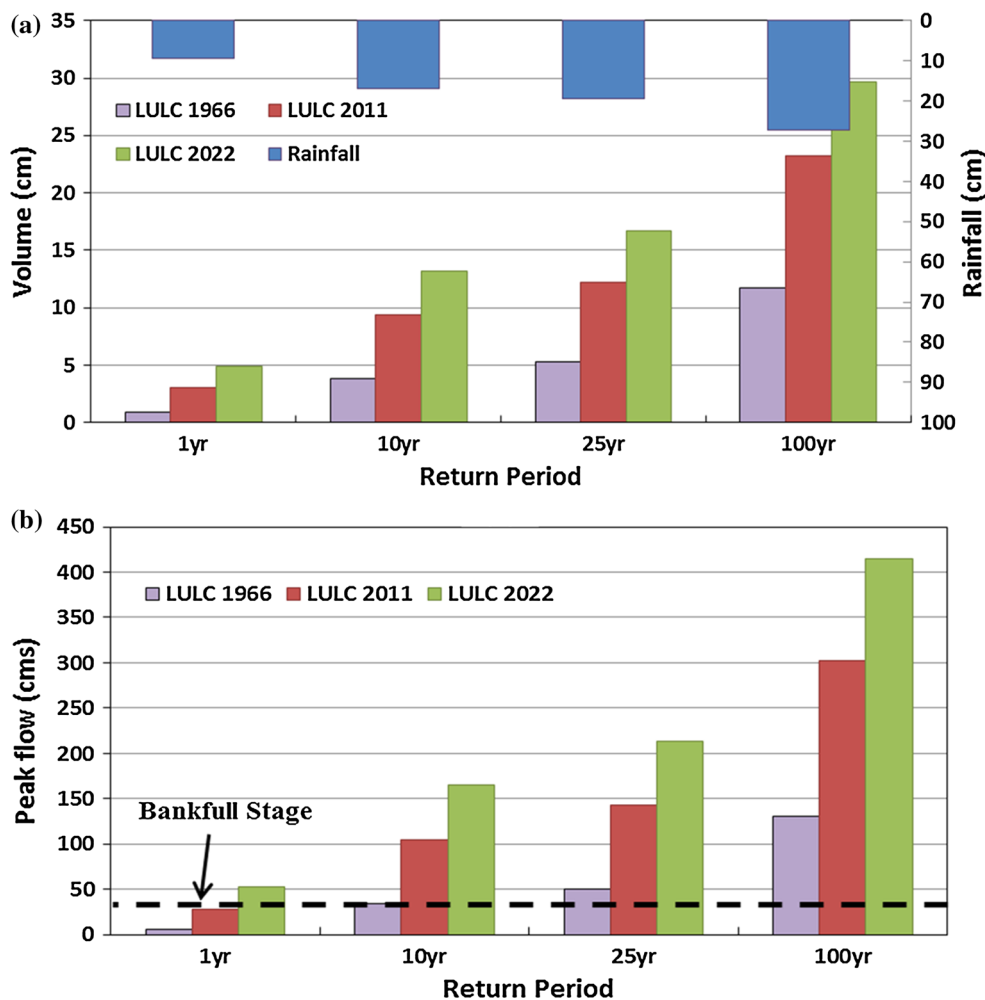


Fig. 7 Ω (a) and ψ (b) values for the flood generating areas (Fig. 3a) under LULC changes from 1966 to 2011

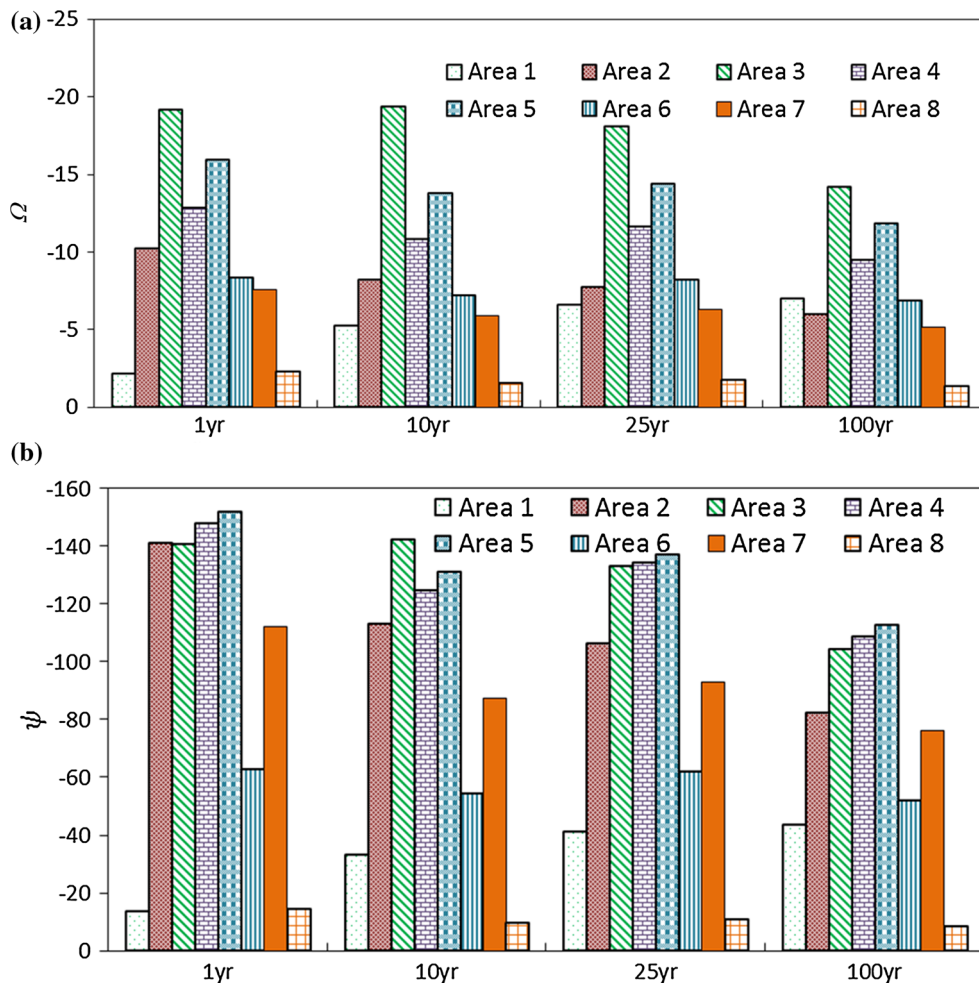


Table 3 Percentage of different LULC types at selected potential flood generating areas in 1966 and 2011

LULC	Flood generating area							
	1 ^c	2	3	4	5	6	7	8
Developed ^a (%)	[2,24] ^b	[2,26]	[3,31]	[4,26]	[3,31]	[6,17]	[2,23]	[18,41]
Imperviousness (%)	[3,14]	[3,14]	[3,18]	[6,23]	[3,17]	[4,10]	[3,14]	[14,26]
Forest (%)	[45,49]	[45,46]	[43,41]	[51,48]	[58,46]	[54,64]	[64,45]	[46,36]
Pasture/hay (%)	[8,4]	[14,2]	[9,1]	[6,3]	[2,3]	[2,1]	[2,2]	[1,1]
Wetland (%)	[13,4]	[14,11]	[19,6]	[10,6]	[7,8]	[12,18]	[9,8]	[7,7]
Open space (%)	[23,4]	[8,4]	[15,4]	[14,9]	[12,5]	[10,2]	[12,7]	[26,9]
Area (km ²)	13.6	6.2	11.6	7.4	9.0	11.3	5.8	13.6
CN-1966	40	43	46	42	39	41	40	63
CN-2011	54	54	55	54	56	52	50	78

^a Includes low, medium and high intensity

^b [Percent of LULC type in 1966, percent of LULC type in 2011]

^c Flood generating area

CN curve number

and temporal scales, climate variability, landscape physiography and physical characteristics of the study area (Zhou et al. 2013).

Figure 7b shows the ψ indexes for each of the eight areas, which are again Ω values normalized with percent area. Accordingly, LULC changes from 1966 to 2011 in Areas 2,

Table 4 Percentage of different LULC types in sub-watersheds located inside the 11 potential flood generating areas in 2011 and 2022

LULC	Flood generating area										
	1 ^c	2	3	4	5	6	7	8	9	10	11
Developed ^a (%)	[19,54] ^b	[41,45]	[29,51]	[22,37]	[26,48]	[18,50]	[18,55]	[12,37]	[13,42]	[16,42]	[30,43]
Imperviousness (%)	[20,34]	[20,28]	[19,32]	[13,23]	[16,29]	[22,31]	[12,34]	[10,23]	[51,77]	[21,27]	[24,28]
Forest (%)	[51,30]	[34,37]	[43,27]	[48,33]	[44,29]	[46,18]	[48,14]	[49,25]	[52,26]	[52,29]	[44,31]
Pasture/hay (%)	[8,3]	[3,2]	[5,5]	[5,5]	[1,1]	[0,0]	[1,1]	[1,1]	[1,1]	[1,1]	[1,1]
Wetland (%)	[3,2]	[2,4]	[6,6]	[8,8]	[12,12]	[26,26]	[28,28]	[29,29]	[22,22]	[18,18]	[11,11]
Open space (%)	[6,6]	[12,7]	[7,7]	[4,4]	[6,4]	[3,2]	[2,1]	[1,1]	[2,2]	[3,3]	[7,7]
Area (km ²)	2.9	5.3	4.6	2.2	9.3	7.5	4.5	3.1	7.4	9.1	18.0
CN-2011	60.0	55.1	54.6	49.3	55.5	64.2	58.8	58.5	62.9	60.6	72.0
CN-2022	63.5	58.7	65.8	57.6	63.0	70.4	71.8	65.7	66.2	65.9	74.0

^a Development with low, medium and high intensity

^b [Percent of LULC type in 2011, percent of LULC type in 2022]

^c Flood generating area

3, 4 and 5 had the largest impact on downstream peak flow. Even after area adjustments, Areas 3, 4 and 5, which are all situated in west-central part of the watershed (Fig. 3a), are still on top of the list. Although percent increase in imperviousness is high in Area 8 (+12 %), LULC change from 1966 to 2011 in this area had the lowest contribution to peak flow increase. Because this area is located close to the downstream, the LULC change impact appears at the rising stage of the flow hydrograph, and not affecting the peak as much. The spatial scale and landscape patterns influence the magnitude of urbanization impacts on physical stream conditions (McBride and Booth 2005).

With increasing storm return period, the relative impact of LULC changes on downstream peak flow from 1966 to 2011 diminishes in almost all areas except in Area 1 (Fig. 7), the most upstream one. This could be a result of the complex interaction between watershed topology (consider travel time) and the non-uniform rainfall distribution. Increase in sensitivity of hydrologic response to land use change with decreasing storm recurrence interval is supported by other studies (Saghafian et al. 2008; Chen et al. 2009; Amini et al. 2011; Olang and Furst 2011). In these studies, the relative increases in the simulated peak discharges diminished with increasing rainfall amounts.

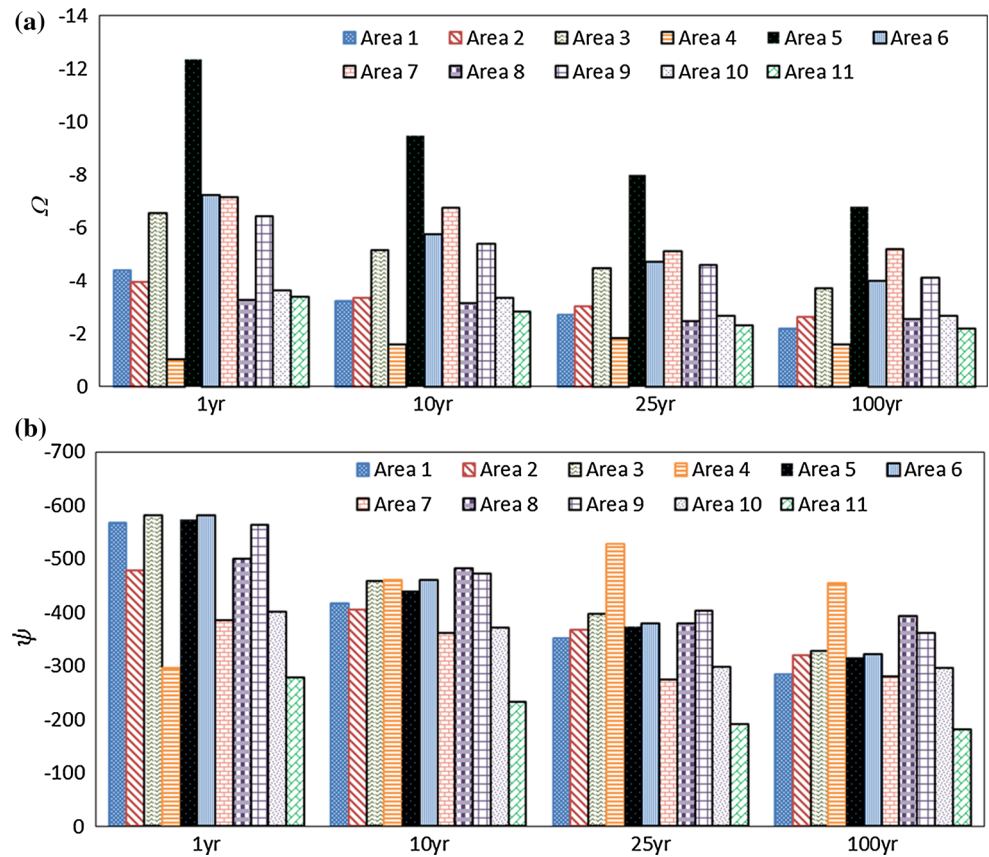
2011–2022

Applying the index method to the historical LULC change condition provided an overall view of how urbanization during this period would affect the downstream peak flow and how peak flows could have been different if certain parts of the watershed were protected. In the next step, the impacts of LULC change from 2011 to 2022 were assessed. The 2022 LULC projects an additional 17 % development

with medium intensity mainly in central part of the watershed. As shown in Fig. 3b, 11 flood generating areas were identified for this assessment (Table 4).

According to Fig. 8a, Area 5, which has the second largest area, is expected to have a big impact on the downstream peak flow and Area 4, which has the smallest area, is expected to have the least impact. Although Area 11 has the largest area, the impact of LULC changes in this area appears at the raising stage of the flow hydrograph, which is likely due to its close proximity to the downstream site. The area normalized index in Fig. 8b tells a slightly different story. None of the areas isolate itself from the rest as the most sensitive area. On average, imperviousness in most areas increased about 12.2 % from 2011 to 2022, mostly due to forest-to-urban conversion. Deforestation and decrease in natural forest cover are known to increase flood frequency (Bradshaw et al. 2007). The ψ values also reflect how location of development plays an important role in increasing peak flow per unit area. For instance, based on the ψ value, Area 4 for storms with 25- and 100-year return periods is the most sensitive area. On the other hand, based on Ω values, the size of development has significant impact on increasing downstream peak flow; therefore, Area 4 was the least critical flood generating area according to Fig. 8a. This area is located at the upstream part of the watershed and is part of the city of Semmes, indicating that even developments in this city can increase the flood risk in city of Prichard, which is at the downstream end of the watershed. Area 4 is projected to have an additional 10 % impervious surface by year 2022. This number is less than the projected increase in imperviousness in Areas 1, 3, 5, 7, 8 and 9 (all coming from forest loss), and yet, somehow Area 4 is the most sensitive area under 25- and 100-year storms based on the ψ index. This

Fig. 8 Ω (a) and ψ (b) values for the flood generating areas (Fig. 3b) under LULC changes from 2011 to 2022



is evidently the result of complex interactions among rainfall intensity and duration, geological composition, watershed steepness and topology, and soil characteristics. Since the relative roles of these factors in flooding vary spatially, understanding the effects of forest loss and generally vegetation removal on flood risk requires more detailed studies (Bradshaw et al. 2007). Our study reveals that both location and extent of development play important roles in potential flooding at the area of interest.

Figure 8 shows that with increasing storm depth, the relative impact of LULC changes from 2011 to 2022 on peak flow in each area decreases except in Area 4. For 25- and 100-year return period storms, Area 4, the most upstream area, has the largest impact on downstream peak flow, and Area 11, the most downstream area, has the least impact on peak flow. Area 11 is the closest to the downstream and likely contributes too quickly to the flow hydrograph. Therefore, urbanization in this area will not have a noticeable impact on peak flow.

Summary and conclusions

In this paper, we attempted to evaluate the LULC changes over time and ranked different parts of the EMC watershed based on their contribution to flooding at a flood-prone area

by conducting a modeling effort. Historical LULC maps were developed by processing aerial photographs in *eCognition* and ArcGIS, and future LULC map was developed with feedbacks from the city of Prichard. The HEC-HMS model was applied as a rainfall–runoff model to explore the LULC–flooding nexus.

There was a large increase in peak flow and runoff volume at the identified downstream site in response to urbanization from 1966 to 2011 and then from 2011 to 2022. The increase was more significant for peak flow than for runoff volume. Also, the degree of impact on runoff volume and peak flows is dependent on the storm magnitude, with smaller return period storms being more sensitive to LULC change, especially urbanization.

Different parts of the watershed ranked based on their sensitivity to historic and future LULC changes. Results showed that development in west-central part of the watershed from 1966 to 2011 had the largest contribution to downstream flooding. Also, future developments concentrated in central parts of the watershed could have significant impacts on peak flows at downstream locations. Increase in storm return periods did not change the order of importance of flood generating areas significantly.

Results of this study clearly showed that even if there is same level of urbanization at different parts of a watershed, their contribution to peak flow at a downstream point

depends on their locations within the watershed. In addition, topography, soil type and roughness play important roles in flooding. Understanding the effects of urban growth on hydrological processes is essential for urban planning. The index method utilized in this study can identify the zones with high peak flow production in downstream of the watershed, and this information can assist urban planners and related decision makers. Applying the index method to the future urban development would provide essential information to anticipate future impacts and to reduce their potential detrimental consequences.

Acknowledgments This work is a result of research sponsored by the National Oceanic and Atmospheric Administration, Department of Commerce, the Mississippi-Alabama Sea Grant Consortium (Grant Number NA10OAR4170078) and the Center for Environmental Studies at the Urban–Rural Interface, Auburn University. The help of Rajesh Sawant who developed the LULC maps from aerial photographs is greatly appreciated.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Ali M, Khan SJ, Aslam I, Khan Z (2011) Simulation of the impacts of land-use change on surface runoff of Lai Nullah Basin in Islamabad, Pakistan. *Landsc Urban Plan* 102(4):271–279. doi:10.1016/j.landurbplan.2011.05.006
- Amini A, Ali TM, Ghazali AHB, Aziz AA, Akib ShM (2011) Impacts of land use change on streamflow generation in Damansara watershed, Malaysia. *AJSE* 36:713–720. doi:10.1007/s13369-011-0075-3
- Anderson J, Hardy E, Roach J, Witmer R (1976) A land use and land cover classification system for use with remote sensor data. U.S. Geological Survey professional paper, vol. 964. 28 pp
- Baltas EA, Dervos NA, Mimikou MA (2007) Technical note: determination of the SCS initial abstraction ratio in an experimental watershed in Greece. *Hydrol Earth Syst Sci* 11:1825–1829. doi:10.5194/hess-11-1825-2007
- Birkinshaw SJ, Bathurst JC, Iroume A, Palacios H (2011) The effect of forest cover on peak flow and sediment discharge—an integrated field and modeling study in central-southern Chile. *Hydrol Process* 25:1284–1297. doi:10.1002/hyp.7900
- Boggs JL, Sun G (2011) Urbanization alters watershed hydrology in the Piedmont of North Carolina. *Ecology* 4(2):256–264. doi:10.1002/eco.198
- Bradshaw CJA, Sodhi NS, Peh KSH, Brook BW (2007) Global evidence that deforestation amplifies flood risk and severity in the developing world. *Glob Change Biol* 13(11):2396–2410. doi:10.1111/j.1365-2486.2007.01446.x
- Chen Y, Xu Y, Yin Y (2009) Impacts of land use change scenarios on storm-runoff generation in Xitiaoxi basin, China. *Quat Int* 208(1–2):121–128. doi:10.1016/j.quaint.2008.12.014
- Definiens (2009) eCognition developer 8.0 user guide. Definiens AG, Munich
- Dixon B, Earls J (2012) Effects of urbanization on streamflow using SWAT with real and simulated meteorological data. *Appl Geogr* 35(1–2):174–190. doi:10.1016/j.apgeog.2012.06.010
- Du J, Qian L, Rui H, Zuo T, Zheng D, Xu Y, Xu Ch-Y (2012) Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China. *J Hydrol* 464–465:127–139. doi:10.1016/j.jhydrol.2012.06.057
- Environmental Systems Research Institute (ESRI) (2010) ArcGIS 10.0 tutorial. Copyright 1999–2010
- Eshleman KN (2004) Hydrological consequences of land use changes: a review of the state-science. American Geophysical Union, Washington. doi:10.1029/153GM03
- Flanders D, Hall-Beyer M, Pereverzoff J (2003) Preliminary evaluation of eCognition object based software for cut block delineation and feature extraction. *Can J Remote Sens* 29(4):441–452. doi:10.5589/m03-006
- Fu S, Zhang G, Wang N, Luo L (2011) Initial abstraction ratio in the SCS-CN method in the Loess Plateau of China. *Trans ASABE* 54(1):163–169. doi:10.13031/2013.36271
- Gao GY, Fu BJ, Lu YH, Liu Y, Wang S, Zhou J (2012) Coupling the modified SCS-CN and RUSLE models to simulate hydrological effects of restoring vegetation in the Loess Plateau of China. *Hydrol Earth Syst Sc* 16:2347–2364. doi:10.5194/hess-16-2347-2012
- Hawkins RH, Ward TJ, Woodward DE, Van Mullen JA (2009) Curve number hydrology—state of practice. The ASCE/EWRI Curve Number Hydrology Task Committee, Reston. doi:10.1061/9780784410042.bm
- Jiang R (2001) Investigation of runoff curve number initial abstraction ratio. MS thesis, Watershed Management, University of Arizona, 120 pp
- Kalin L, Hantush MM (2009) An auxiliary method to reduce potential adverse impacts of Projected land developments: subwatershed prioritization. *Environ Manag* 43(2):311–325. doi:10.1007/s00267-008-9202-7
- Lin Y-P, Verburg PH, Chang Ch-R, Chen H-Y, Chen M-H (2009) Developing and comparing optimal and empirical land-use models for the development of an urbanized watershed forest in Taiwan. *Landsc Urban Plan* 92:242–254. doi:10.1016/j.landurbplan.2009.05.003
- McBride M, Booth DB (2005) Urban impacts on physical stream condition: effects of spatial scale, connectivity, and longitudinal trends. *JAWRA* 41(3):565–580. doi:10.1111/j.1752-1688.2005.tb03755.x
- Mejia A, Moglen G (2009) Spatial patterns of urban development from optimization of flood peaks and imperviousness-based measures. *J Hydrol Eng* 14(9):416–424. doi:10.1061/(ASCE)1084-0699(2009)14:4(416)
- Mishra AK, Singh VP (2004) Validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates. *Hydrol Process* 18:3323–3345. doi:10.1002/hyp.1223
- Moriassi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans ASABE* 50(3):885–900. doi:10.13031/2013.23153
- Olang LO, Furst J (2011) Effects of land cover change on flood peak discharges and runoff volumes: model estimates for the Nyando River Basin, Kenya. *Hydrol Process* 25:80–89. doi:10.1002/hyp.7821
- Qaiser K, Yuan Y, Lopez RD (2012) Urbanization impacts on flooding in the Kansas River Basin and evaluation of wetlands as a mitigation measure. *Trans ASABE* 55(3):849–859. doi:10.13031/2013.41519
- Saghafian B, Farazjoo H, Bozorgy B, Yazdandoost F (2008) Flood intensification due to changes in land use. *Water Resour Manag* 22:1051–1067. doi:10.1007/s11269-007-9210-z
- Shi ZhH, Chen LD, Fang NF, Qin DF, Cai ChF (2009) Research on the SCS-CN initial abstraction ratio using rainfall-runoff event

- analysis in the Three Gorges Area, China. *Catena* 77(1):1–7. doi:10.1016/j.catena.2008.11.006
- Smith JA, Baeck ML, Morrison JE, Sturdevant-Rees P, Turner-Gillespie DF, Bates PD (2002) The regional hydrology of extreme floods in an urbanizing drainage basin. *J Hydrometeorol* 3:267–282. doi:10.1175/1525-7541(2002)003<0267:TRHOEF>2.0.CO;2
- Taubenbock H, Wurm M, Netzband M, Zwenzner H, Roth A, Rahman A, Dech S (2011) Flood risks in urbanized areas—multi-sensoral approaches using remotely sensed data for risk assessment. *Nat Hazards Earth Syst Sci* 11:431–444. doi:10.5194/nhess-11-431-2011
- Ty TV, Sunada K, Ichikawa Y, Qishi S (2012) Scenario-based impact assessment of land use/cover and climate change on water resources and demand: a case study in the Srepok River basin, Vietnam—Cambodia. *Water Resour Manag* 26:1387–1407. doi:10.1007/s11269-011-9964-1
- U.S. Census Bureau (2011) Census 2010. <http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>
- Verbeiren B, Van De Voorde T, Canters F, Binard M, Cornet Y, Batelaan O (2013) Assessing urbanization effects on rainfall-runoff using a remote sensing supported modeling strategy. *Int J Appl Earth Obs Geoinf* 21:92–102. doi:10.1016/j.jag.2012.08.011
- Verma AK, Jha MK, Mahana RK (2010) Evaluation of HEC-HMS and WEPP for simulating watershed runoff using remote sensing and geographical information system. *Paddy Water Environ* 8:131–144. doi:10.1007/s10333-009-0192-8
- Wan R, Yang G (2007) Influence of land use/cover change on storm runoff—a case study of Xitiaoqi River basin in upstream of Taihu Lake Watershed. *Chin Geogr Sci* 17(4):349–356. doi:10.1007/s11769-007-0349-6
- Woods and Poole Economics, Inc. (2011) Complete economic and demographic dataset. <http://www.woodsandpoole.com/main.php?cat=country>. Data processed by NOAA to determine coastal county summary totals and absolute and percent change
- Woodward DE, Hawkins RH, Jiang R, Hjelmfelt Jr AT, Van Mullem JA, Quan QD (2003) Runoff curve number method: examination of the initial abstraction ratio. In: *World water and environment resources congress 2003 and related symposia*, pp 1–10. doi:10.1061/40685(2003)308
- Zhang Y, Shuster W (2014) Impacts of spatial distribution of impervious areas on runoff response of hillslope catchments: simulation study. *J Hydrol Eng* 19(6):1089–1100. doi:10.1061/(ASCE)HE.1943-5584.0000905
- Zhou F, Xu Y, Chen Y, Xu C-Y, Gao Y, Du J (2013) Hydrological response to urbanization at different spatio-temporal scales simulated by coupling of CLUE-S and the SWAT model in the Yangtze River Delta region. *J Hydrol* 485:113–125. doi:10.1016/j.jhydrol.2012.12.040