Nat Hazards (2015) 76:1457–1471
DOI 10.1007/s11069-014-1463-2

ORIGINAL PAPER

Quantifying the impact of impervious surface location on flood peak discharge in urban areas

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Received: 18 March 2014 / Accepted: 29 September 2014 / Published online: 30 January 2015

Abstract To date, limited attention has been paid to the role of impervious surface (IS) location in influencing flood processes. However, this topic is of tremendous significance for developing guidelines for urban planning and flood management. This study uses the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) to investigate the impact of land-use change on flood processes and proposes a new index to quantify the impact of IS location on basin peak discharge. The results indicate that rapid urban expansion in the Longhua Basin, China, has increased peak discharge and flood volume by 140 and 162 % over the past 30 years, respectively. The new index, named the Impervious Surface Impact Index, describes the spatially varying effects of IS increase in individual sub-basins on a basin's peak discharge. For the Longhua Basin, the index varies from 0.43 in downstream sub-basins to 5.91 in upstream sub-basins. An increase in upstream IS increases peak discharge nearly 14 times more than the same increase in downstream IS. Accordingly, the location of newly created IS can influence flood processes significantly. These findings can help to find suitable locations for urban development while mitigating the impact of land development on flood risks.

Electronic supplementary material The online version of this article (doi:10.1007/s11069-014-1463-2) contains supplementary material, which is available to authorized users.

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Keywords Peak flow · Flood risk · Impervious surface · Low-impact development · Flood mitigation

1 Introduction

Converting land to feed and shelter a growing population has been one of the primary ways humans have modified the global environment (DeFries and Eshleman 2004; Foley et al. 2005). Since the beginning of the twentieth century, an accelerated urbanization process has been spreading from the developed world to developing countries (Grimm et al. 2008; Lambin et al. 2001; Seto et al. 2011). At present, the urbanization process is unprecedented in countries such as China, which presents not only an opportunity for economic growth but also a challenge to sustainable and safe urban development (Bai et al. 2014). Rapid urbanization brings about environmental chaos at multiple scales, ranging from local urban heat islands (Kalnay and Cai 2003) and alterations of hydrological processes and water resources (Bosch and Hewlett 1982; Gueneralp and Seto 2008) to global climate change (Karl and Trenberth 2003) and long-term extinction of species (Nelson et al. 2010).

The impacts of urbanization on hydrological processes have been intensively studied and have been mainly attributed to the expansion of impervious surface (IS) areas (Bosch and Hewlett 1982; DeFries and Eshleman 2004). In general, IS increase can affect hydrological processes and increase peak discharge in four ways. First, clearing vegetation for urban development decreases transpiration, and paving urban surfaces decreases soil evaporation (Bosch and Hewlett 1982). Second, ISs drastically lower total infiltration, and thus significantly amplify infiltration-excess precipitation and direct runoff (Gilroy and McCuen 2012). Third, paving with impervious materials and installing sewers and storm drains decreases the roughness of runoff routing, which shortens the concentration time of overland flow as well as the lag time between precipitation and peak discharge (Liu et al. 2003). Fourth, the combined effects of increased runoff generation and decreased concentration time can magnify peak discharge and the associated flood risk (Shi et al. 2007).

However, although vital to efficient flood risk management, limited attention has been paid to the impact of IS location on water resources and flooding (Mejia and Moglen 2009). Understanding the spatial variation of IS's impact on flood processes can help minimize negative impacts and optimize land-use distribution (Tang et al. 2005). With regard to flood management, locations where an increase in IS has the lowest impact on flood peak discharge can be regarded as the most suitable location for development (Richert et al. 2011); meanwhile, high-impact locations should be excluded from development or required to employ other strategies for controlling IS-induced increases in peak discharge (Battiata et al. 2010; Hood et al. 2007).

Only a handful of studies have investigated the impact of IS location on flood peak discharge, with somewhat conflicting key findings. Garbrecht (1991) argued that sub-basins near the basin centroid contribute relatively more to a basin's peak flow than sub-basins far from the basin centroid, implying the former should be prevented from development to reduce peak discharge. Yeo and Guldmann (2006) concluded a maximum reduction in peak discharge would occur if built-up lands were distributed in middle-stream areas. Mejia and Moglen (2009) found that the spatial form of IS could affect peak discharge significantly. Yang et al. (2011) found that different locations of built-up land have different impacts on peak discharge and hypothesized that the influence could be largest if water's travel time from urbanized cells is close to the mode of water's travel time from all other cells.

The above findings are in conflict with each other to the extent that, while Yeo and Guldmann (2006) concluded that urbanized areas located upstream and downstream affect peak discharge the most, Garbrecht (1991) and Yang et al. (2011) argued that urbanized cells in middle areas have the most significant impact. Therefore, despite recent progress, the effect of IS location on peak discharge remains to be elucidated. Two main questions remain to be answered. First, is there any location for IS where its impact on peak discharge is much lower than in other places? Second, can this location be investigated via a practicable index? Urban expansion in suitable locations could help mitigate the impact of development on peak discharge. Index-based methods can facilitate such investigations and ensure valid comparisons between studies from different regions.

This study aims to answer the above questions via developing an index to investigate the impact of IS location on flood discharge. To this end, we present a case study of the rapidly urbanizing Longhua Basin in the city of Shenzhen, southern China. After calibrating a HEC-HMS model, we used the model for simulating the urban expansion's influence on flood processes. We then developed an easy-to-use index to quantify the impact of IS location on peak discharge. Finally, we discuss and interpret our findings and their significance for flood management and urban planning.

2 Materials and methods

2.1 Study area

The Longhua Basin is located in the central-western portion of Shenzhen, southern China (Fig. 1). It covers an area of 78 km^2 and comprises the upper reaches of the Guanlan Basin. Elevation ranges from 45 to 520 m. The dominant soil types are lateritic red soil (74 %) and paddy soil (22 %) (GIGS 1983). The area has a subtropical monsoon climate with a mean annual temperature of 22 °C and mean annual precipitation of 1,700 mm. Almost 80 % of the rainfall occurs during April to September and is concentrated in the months of May, June, and July (Shi et al. 2007).

The Longhua Basin has been rapidly urbanizing over the past decades while experiencing more frequent flooding. During 1980–2010, the proportion of built-up land increased from 0.10 to 63.40 % (Shi et al. 2007; Du et al. 2014). This rapid urbanization has had a significant effect on hydrological processes and associated flood risks in the area. While it was once recognized as relatively flood-proof (Chen 2003), the area is now prone to flooding (CHES 2010). Reducing the exacerbated flood risk requires substantial funds to reinforce the flood defense system (Cheng et al. 1995). Fortunately, increasing attention is being paid to the role of land-use systems in managing flood risk (Shi et al. 2005), which can be a more cost-effective method than traditional structural measures such as dykes and dams (European-Commission 2007). However, there is still a need for additional research, especially with regard to placing the IS in suitable locations for reducing flood risk.

2.2 HEC-HMS model

The HEC-HMS model (Hydrologic Modeling System, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers) was employed to analyze storm rainfall discharge and its sensitivity to the location of IS. The HEC-HMS represents

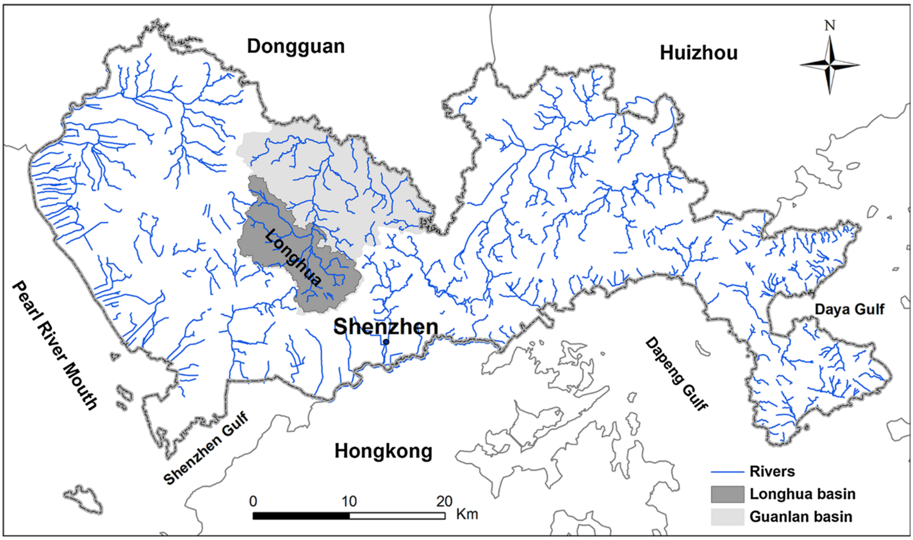

Fig. 1 Location of the Longhua Basin

hydrological elements as sub-basins, reaches, and junctions (Fig. 2). It simulates the runoff process within those elements with four sub-models, namely excess precipitation computation, direct runoff generation, base flow estimation, and channel routing. Excess precipitation is computed by means of the Soil Conservation Service (SCS) method, which can be written as follows (USDA 1972):

$$\begin{cases} Q = \dfrac{(P - 0.2S)^2}{P + 0.8S}, & P \geq 0.2S \\ Q = 0, & P < 0.2S \end{cases} \tag{1}$$

where Q (mm) is direct runoff and P (mm) is precipitation. S is potential maximum retention or infiltration that describes a land unit's ability to retain storm precipitation. It can be estimated using a dimensionless runoff curve number (CN) with $S = (25{,}400/CN) - 254$, whereby CN can be assigned to each land unit on the basis of the antecedent moisture, soil, and land-use properties according to lookup tables (USDA 1972).

Direct runoff is estimated via the Clark unit hydrograph model (Clark UH). It employs a time–area histogram to translate excess precipitation from its origin throughout the drainage system to sub-basin outlets. The time–area histogram estimates direct runoff based on the instantaneous cumulative area in each sub-basin, from which excess precipitation contributes to runoff at the outlet at a specific time (Jakeman et al. 1990). HEC-HMS expresses this process as follows:

$$\frac{A_\mathrm{t}}{A} = \begin{cases} \sqrt{2}(t/tc)^{1.5} & , \; for \quad t \leq 0.5tc \\ 1 - \sqrt{2}(1 - t/tc)^{1.5} & , \; for \quad t > 0.5tc \end{cases} \tag{2}$$

where A_t is the cumulative area in a sub-basin at time t above which excess precipitation contributes to flow at the corresponding outlet; A is the total area of the sub-basin; and t_c is the concentration time of the sub-basin.

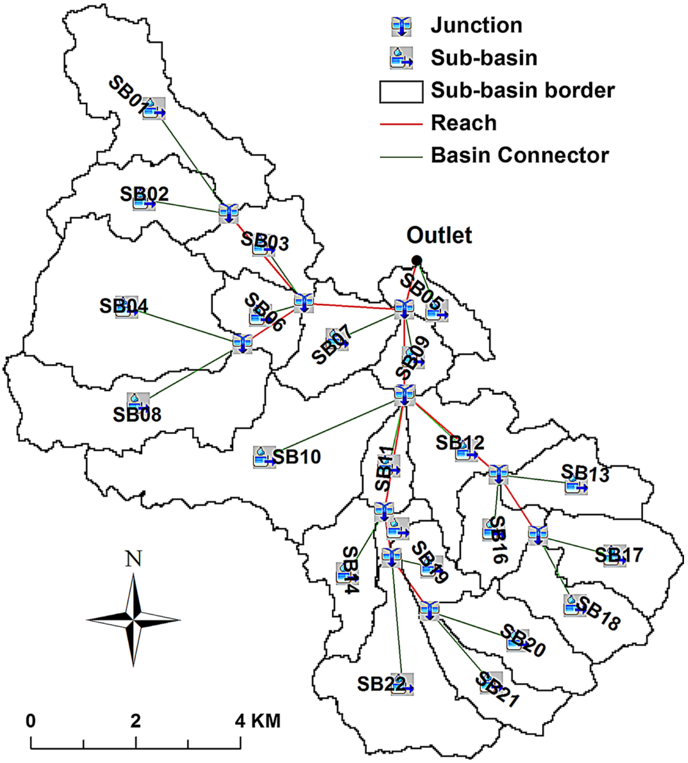

Fig. 2 Schematic map of hydrologic elements in the HEC-HMS model

The Muskingum method was adopted to model the channel flow from sub-basin outlets to the basin's outlet. It expresses the instantaneous outflow as follows:

$$\begin{gathered} Q_t = C1It + C2It - 1 + (1 - C1 - C2)Q_t - 1 \\ C1 = \frac{\Delta t - 2kx}{2k(1-x) + \Delta t}, C2 = \frac{\Delta t + 2kx}{2k(1-x) + \Delta t} \end{gathered} \tag{3}$$

in which I_{t-1}, I_t are inflows to the routing reach at times $t-1$ and t, respectively; Q_{t-1} and Q_t are outflows from the routing reach at times $t-1$ and t, respectively. C_1 and C_2 are parameters expressing how current inflow, I_t, and the balance between previous inflow and outflow, I_{t-1} and Q_{t-1}, determine current outflow, Q_t. Δt is the computation interval; k is the travel time of the flood wave through the routing reach; and x is a dimensionless weight.

2.3 Data for model calibration

Geo-HMS 5.0, an application in ESRI ARCGIS 10, was used to construct the HEC-HMS model (USACE-HEC 2010). The procedure mainly used a river's shape data and a digital elevation model (DEM), produced from a 1:10 000 scale contour map, provided by Shenzhen's Water Planning & Design Institute and Shenzhen's Urban Planning & Land-Resource Commission, respectively. The same data were also used to estimate parameters for the hydrological elements. The contour map helped to estimate the initial concentration time for each sub-basin, and the river's shape data produced the parameters for Muskingum routing (USACE-HEC 2000).

A 1:200 000 scale soil map (GIGS 1983) and land-use maps from 1980, 1988, 1994, 2000, 2005, and 2010 (Shi et al. 2007; Du et al. 2014) were used to produce CN values for each grid (30 m × 30 m). The two datasets as well as the DEM are shown in Fig. 3. The land-use maps were also used to produce impervious ratios for the sub-basins. The maps divided built-up land (BUL) into high-density BUL and low-density BUL (Shi et al. 2007). Impervious ratios for the two kinds of BUL were set as 98 and 80 %, respectively. A calibration was then implemented based on measured 5-min-interval rainfalls and 30-min-interval river flows. Rainfall and river flow data were provided by Shenzhen's Meteorological Bureau and Shenzhen's Water Planning & Design Institute, respectively. They contained four flood events (Table 1). Two events were employed to calibrate the initially estimated parameters using HEC-HMS's automatic optimization tool. The other two events were used to verify the model.

2.4 Impervious surface impact index (ISII)

An Impervious Surface Impact Index (ISII) was developed to quantify the impact of IS location on the basin's peak discharge. The index is designed to rank the impact of sub-basins' IS increase on the basin's peak discharge. If ISs located in different sub-basins have significantly different impacts on the basin's peak discharge, then this index can help to find suitable locations for development and conservation while mitigating flood risks.

The modeling procedure first sets a null scenario of land-use condition, which feeds the HEC-HMS model and produces the null peak discharge, Q. Next, the procedure increases the IS ratio for one sub-basin (k) while keeping all other sub-basins in the null land-use scenario, which is named scenario k (Sk). The changed land-use condition feeds the hydrological model and produces the peak discharge $Q(k)$. This procedure can thus detect variations in peak discharge caused by the IS increase in sub-basin k. The ISII score for sub-basin k is the changed peak discharge divided by the IS increase in the sub-basin. The score can be expressed as follows:

$$ISII(k) = \frac{Q(k) - Q}{Q \times (IS(k) - IS)} \times 100\% \tag{4}$$

where $ISII(k)$ is the ISII score for sub-basin k; Q is the basin peak discharge when all sub-basins are under the null land-use scenario; $Q(k)$ is the basin peak discharge when IS changes in sub-basin k; $IS(k)$ and IS are IS areas in sub-basin k under scenario k and under the null scenario, respectively.

The null land-use scenario was derived from the land-use map of 1980. Scenario k then increased the IS area in sub-basin k by 1 km^2, while keeping other sub-basins under null scenario conditions. Because the spatial–temporal distribution of rainfall events has a potential impact on the flood flow (Mejia and Moglen 2010), the ISII may vary with different rainfall events. Therefore, the ISII will produce more useful results when calculated for the most predominant rainfall scenario. In this study, the IISI was calculated for a 2-year-return rainfall scenario with a total precipitation of 78.6 mm over 3 h, which was estimated by Shenzhen's Water Planning & Design Institute.

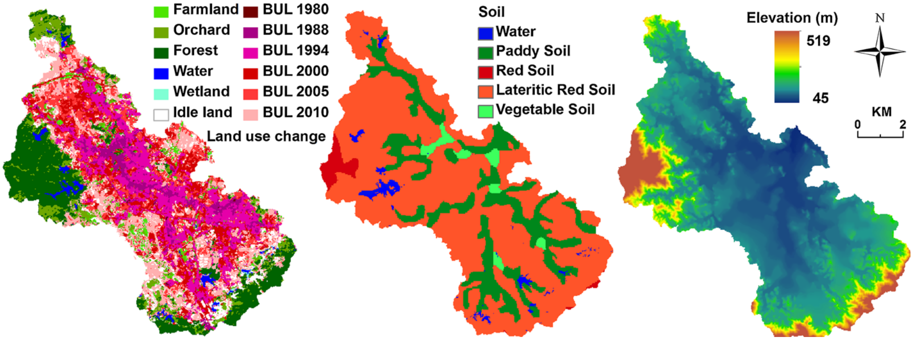

Fig. 3 Land-use change, soil, and elevation maps for the Longhua Basin

Table 1 Measured flood discharge data

Storms	Date	Calibration or validation
Storm 1	00:00, May 31, 2008–00:00, June 02, 2008	Calibration
Storm 2	00:00, June 02, 2008–00:00, June 03, 2008	Calibration
Storm 3	00:00, June 06, 2008–00:00, June 08, 2008	Validation
Storm 4	00:00, June 11, 2008–00:00, June 12, 2008	Validation

3 Results

3.1 Calibration and validation of HEC-HMS

The HEC-HMS model was calibrated and verified separately for the four observed rainfall-discharge events (Fig. 4; Table 2). The modeled discharge after calibration agreed well with the observed flood flow for both calibration events (Storms 1 and 2). The correlation coefficients for simulation results and observed data are higher than 0.98 for both calibration events, with a significance level of 0.001 in a two-tailed test. The differences of peak discharge and total flow between the two events were both less than 20 %. The calibrated parameters are listed in Supplementary Tables S1 and S2.

Additionally, the model's performance was verified by validation events (Storms 3 and 4). Using the calibrated parameters and the validation rainfall-discharge events, the model successfully simulated the flood discharge. The correlation coefficients for simulated and observed flow data are higher than 0.95 for both events, with a significance level of 0.001 in a two-tailed test. Differences in peak discharge and total flow between simulated results and observed data are <20 %.

3.2 Impact of detected land-use changes on flood processes

Using the precipitation scenario of Storm 4, the calibrated HEC-HMS model was applied to simulate the discharge response to the recorded land-use conditions. The results indicate that land-use change in the Longhua Basin significantly increased peak discharge and flood volume (Fig. 5a; Table 3). With unchanged precipitation, land-use change between 1980

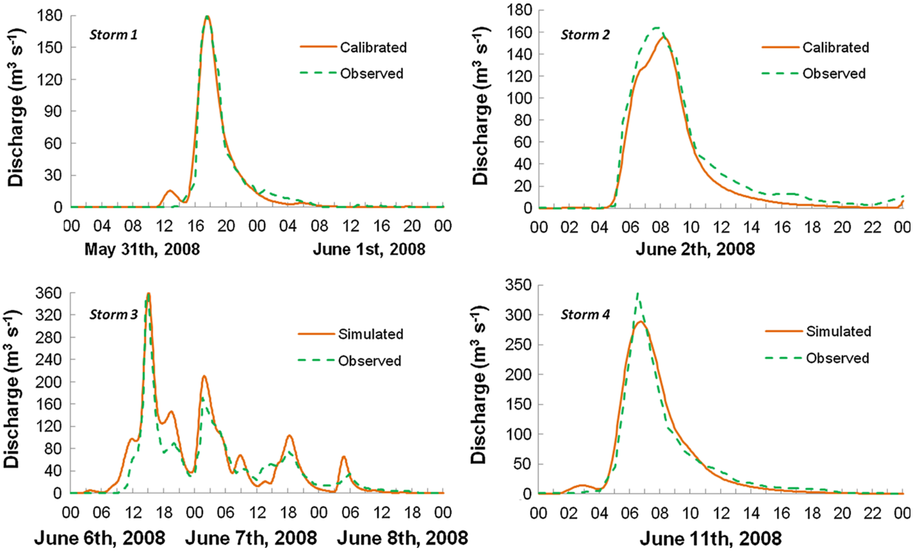

Fig. 4 Comparison of observed and computed stream flow for four flood events

Table 2 Comparison of observed and computed stream flow for four flood events

	Peak discharge ($m^3\ s^{-1}$)				Flood volume ($10^6\ m^3$)			
	Storm 1	Storm 2	Storm 3	Storm 4	Storm 1	Storm 2	Storm 3	Storm 4
Simulated	179.90	155.50	362.00	288.50	2.65	2.43	13.34	4.43
Observed	180.10	164.40	356.90	335.90	2.62	2.99	11.29	4.21
Difference (%)	−0.11	−5.41	1.43	16.43	1.15	−18.73	18.18	4.97

and 2010 increased flood volume and peak discharge by 162 and 140 %, respectively, and shortened the lag time from precipitation to peak discharge by 35 min.

In the past 30 years, more than 63 % of the land was converted from natural and agricultural covers that can intercept, store, and transport water to a paved, urban, and impermeable surface. This process more than doubled flood volume and peak discharge and, in turn, flood risk. The increases in flood volume and peak discharge are correlated with impervious ratios at a significance level of 0.01 (Fig. 5b). Urban expansion in the Longhua Basin thus markedly magnified flood discharge. This magnification plausibly caused the exacerbated flooding in this region during the past decades.

3.3 Impact of IS location on peak discharge in two different sub-basins

The ISII value in Fig. 6 indicates that an increase in IS in different sub-basins affects the basin's peak discharge in different ways. The index varies from 0.43 % for downstream sub-basins to 5.91 % for upstream sub-basins. Any upstream urban expansion would thus lead to a much stronger increase in peak discharge at the basin's outlet than its downstream counterpart would. Therefore, the location of new IS has a significant impact on flood discharge.

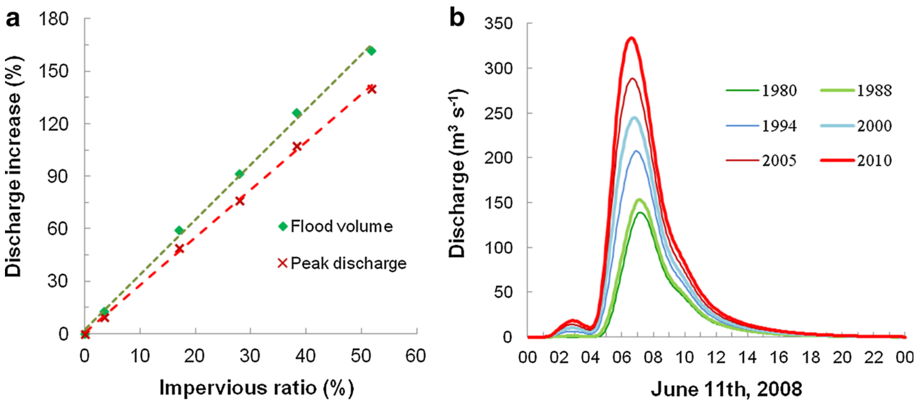

Fig. 5 Flood flow variation with land-use change from 1980 to 2010

Table 3 Flood flow variation with land-use change from 1980 to 2010

	1980	1988	1994	2000	2005	2010
Peak discharge (m^3 s^{-1})	139.10	152.40	207.60	244.80	288.50	333.90
Peak Time	07:10	07:10	06:55	06:50	06:40	06:35
Flood volume (10^6 m^3)	1.82	2.05	2.90	3.48	4.12	4.76

Sub-basin (SB) 05 and SB17 were selected to investigate the impact of IS increase in sub-basins on the hydrographs of both the sub-basins and the basin as a whole. The sub-basin hydrograph shows a similar response to the IS increase (Fig. 7a). One square kilometer increase in IS increases the peak discharge of the two sub-basins by 3.50 and 4.70 m^3 s^{-1}, corresponding to increases of 59.32 and 69.12 %, respectively. In contrast, the basin's flood flow shows different variations in response to IS increases in the two sub-basins (Fig. 7b). The IS increase in SB05 mainly affects the first 3 h of the flood discharge (green line), while its influence is very limited during the basin's peak discharge time, increasing the peak discharge by only 0.43 %. However, the IS increase in SB17 increases the basin's peak discharge by 5.91 % (red dashed line), which is nearly 14 times more than the increase caused by the IS increase in SB05.

4 Discussion

4.1 The impact of IS location on basin peak discharge

The hydrological modeling and ISII proposed in this study demonstrate that the impact of IS on basin peak discharge varies among sub-basins. While ISs in sub-basins have similar impacts on their respective sub-basin hydrographs and peak discharges, they do have significantly different impacts on the hydrograph and peak discharge of the basin as a whole. More specifically, the impact of IS increase on basin peak discharge is not only determined by how much a new IS can increase runoff, but also by when the increased runoff joins the basin's flow. A sub-basin's urbanization causes the largest increase in the

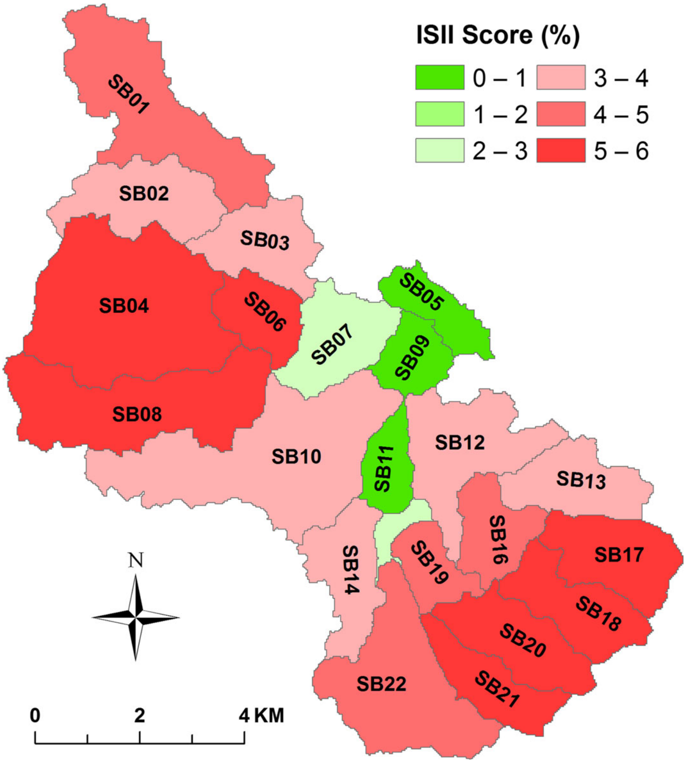

Fig. 6 ISII scores for each sub-basin

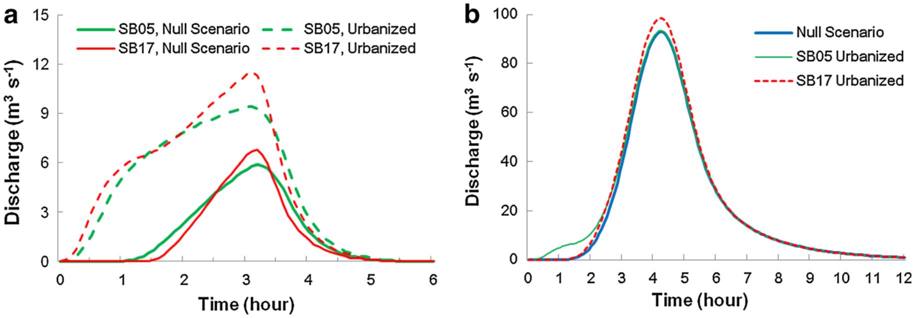

Fig. 7 Impacts of sub-basin IS increase on flood flows in the sub-basins (**a**) and the entire basin (**b**)

basin's peak discharge if the majority of the increased runoff coincides with the basin's peak discharge (Fig. 8). By contrast, the increase in basin peak discharge is relatively small if the majority of the increased runoff joins the leading edge of the basin flow. Therefore, our hydrological simulation and proposed index highlight the impact of IS location on flood flow and peak discharge.

However, several factors may affect the index, which need further investigation. In addition to the spatial–temporal distribution of IS, watershed and rainfall characteristics

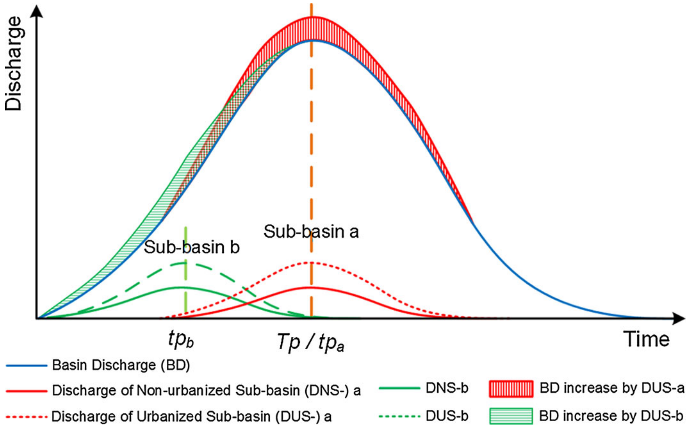

Fig. 8 Sketch of different impacts on flood flow caused by IS increases in different basin locations

could potentially influence the effect of urban expansion on hydrological processes (Bosch and Hewlett 1982; Mejia and Moglen 2010). The index's value may vary from watershed to watershed, due to size, shape, topography, river network, and other characteristics of a watershed. Additionally, intensity, duration, and the spatial–temporal distribution of rainfall events can also affect the index's value (Mejia and Moglen 2010). Accordingly, the sub-basin whose IS has the highest impact on basin peak discharge can be upstream, middle stream, or downstream, depending on the specific watershed and the rainfall characteristics. These factors may have led to the differing conclusions reached by Yeo and Guldmann (2006) and Yang et al. (2011). Yeo and Guldmann (2006) concluded a maximum reduction in peak discharge would occur if BULs were distributed in middle-stream areas, while Yang et al. (2011) hypothesized that sub-basins far from the basin centroid contribute relatively less to the basin peak flow than sub-basins near the basin centroid.

4.2 Application of the IISI for urban planning and flood mitigation

In past decades, an unprecedented urbanization process has spread around the globe, affecting developing countries in particular (Grimm et al. 2008; Lambin et al. 2001; Seto et al. 2011). By 2050, more than 95 % of the net increase in global population will occur in cities of the developing world (UNPD 2012). In China, nearly 300 million new residents will live in cities by 2050. This process of rapid urban expansion will bring about a massive increase in IS, with a concurrent exacerbation of urban flood risks, because any increase in IS will significantly enlarge direct runoff and peak discharge (Richert et al. 2011). Our results agree with previous studies on the impact of increased IS on direct runoff and peak discharge. Furthermore, we have shown that IS location has a significant impact on peak discharge. These findings can help to better understand and manage the rising flood risk in urbanized areas.

Structural and non-structural methods have been applied to manage the exacerbated flood risk, with most of the attention focused on structural methods, such as dykes and dams. In applying those methods, the design standard is typically estimated via analyzing precipitation intensity and the associated peak discharge, which assumes the peak discharge of a given precipitation is stationary and independent over time, often overlooking the impact of urban expansion on peak discharge and flood risk. Urban planning and flood management thus do not typically pay enough attention to the urbanization dimension when designing flood defense facilities, which is likely to magnify the flood risk in urban areas (Gilroy and McCuen 2012; Milly et al. 2008). In the Longhua Basin, the effect of urban expansion on peak discharge and flood risk has not sufficiently been taken into account when the flood defense system was designed, which has exacerbated the flood risk (Cheng et al. 1995; Qiu et al. 1998). Therefore, our study is applicable to other rapidly urbanizing cities, which should take into account the rising flood flow under future IS scenarios when designing and updating their flood defense facilities.

However, it is typically expensive and difficult to construct new or reinforce existing flood defense facilities. In contrast, non-structural methods are cost-effective ways of achieving flood protection, which profit from nature's own capacity to absorb flood waters (European-Commission 2007). Non-structural methods, e.g., green roofs, bioretention ponds, and permeable pavements, are typically referred to as low-impact development (LID) (Battiata et al. 2010; Hood et al. 2007). Green roofs and permeable pavement can mimic undeveloped land cover in terms of infiltration, evapotranspiration, water storage, and direct runoff, which reduces the effective IS in urban areas, and in turn, controls the impact of IS on flood discharge. Additional measures such as the construction of bioretention ponds can enhance the effect of green land on controlling direct runoff and peak discharge. Therefore, application of LID methods can reduce the effect of IS on flood discharge. However, little attention has been paid to the role played by the location of LID measures in mitigating urban flood flow (Gilroy and McCuen 2009; Damodaram and Zechman 2013; Hood et al. 2007). The proposed index, ISII, can help to find optimal locations for LID measures, maximizing their effect on controlling flood discharge.

For a given flood basin, the location with the lowest ISII value can be viewed as the most suitable site for development, because an IS increase there would have the lowest impact on peak discharge. On the other hand, the location with the highest index value should be protected against development, because any new IS would likely increase peak discharge the most. If locations that scored the highest are to be developed, LID methods should be applied to reduce the increase in peak discharge. Therefore, LID methods will have maximum effect if they are applied in the sub-basin with the highest ISII score. Additionally, this index could also be included in land-use models to facilitate urban planning (Richert et al. 2011; Mitsova et al. 2011). Land-use models typically analyze urbanization scenarios based on probability and suitability of a land unit to be developed (Sante et al. 2010). If the models consider the ISII as a factor for development suitability of a land unit, it could guide urban expansion to areas where an increase in IS would have the lowest impact on flood discharge. As a result, the model would produce a more suitable pattern of BUL from a flood management perspective.

5 Conclusion

This study investigated the impact of IS increase on flood discharge in the Longhua Basin, Shenzhen, China, with special emphasis on the role played by IS location. A calibrated HEC-HMS model revealed that rapid urban expansion increased peak discharge and flood volume by 140 and 162 %, respectively. The proposed ISII was able to describe the effect of IS location on peak discharge, which agrees with the research by Garbrecht (1991) and Yang et al. (2011). The index varied from 0.43 for downstream sub-basins to 5.91 for upstream sub-basins. The higher the ISII, the larger was the increase in the basin's peak discharge, and vice versa. Increased IS in different sub-basins thus affected the basin's peak discharge differently, although it produced similar increases in each sub-basin's peak discharge. The above findings suggest that both the increase in runoff from sub-basins because of new IS and the timing of this runoff joining the main basin's flow determine the impact of new IS on basin's peak discharge. If the increased runoff mainly joins during the basin's peak discharge, the IS increase in the corresponding sub-basin will increase the basin's peak discharge significantly.

The above findings suggest that cities should consider an increase in flood discharge under future IS scenarios when designing new and reinforcing existing flood defense facilities. Today, flood defense facilities include not only structural methods such as dykes and dams, but also non-structural methods such as improved land-use planning and LID (Battiata et al. 2010; Hood et al. 2007; European-Commission 2007). The proposed index, ISII, can help to find suitable locations for land development and LID practices. Locations with the lowest ISII values should be considered as the primary development sites, because an IS increase there would have the lowest impact on peak discharge, while the location with the highest ISII value should be protected against development, because any new IS would likely increase peak discharge the most. If locations that scored the highest are to be developed, LID methods should be applied to reduce the otherwise significant increase in peak discharge. The proposed ISII can also help to find optimal locations for LID methods to support flood management.

Acknowledgments This research is supported by the National Natural Science Foundation of China (Grant No. 41321001 and No. 41401603).

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