Urban stormwater inundation simulation based on SWMM and diffusive overland-flow model

Wenjie Chen, Guoru Huang and Han Zhang

ABSTRACT

With rapid urbanization, inundation-induced property losses have become more and more severe. Urban inundation modeling is an effective way to reduce these losses. This paper introduces a simplified urban stormwater inundation simulation model based on the United States Environmental Protection Agency Storm Water Management Model (SWMM) and a geographic information system (GIS)-based diffusive overland-flow model. SWMM is applied for computation of flows in storm sewer systems and flooding flows at junctions, while the GIS-based diffusive overland-flow model simulates surface runoff and inundation. One observed rainfall scenario on Haidian Island, Hainan Province, China was chosen to calibrate the model and the other two were used for validation. Comparisons of the model results with field-surveyed data and InfoWorks ICM (Integrated Catchment Modeling) modeled results indicated the inundation model in this paper can provide inundation extents and reasonable inundation depths even in a large study area.

Key words | diffusive overland-flow model, GIS, inundation simulation, SWMM, urban stormwater

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INTRODUCTION

With the booming economy in China, rapid urbanization has led to an increase in impervious urban surface areas. In the past three decades, total urban built-up land area expanded from 7,438 km^2 to 45,566 km^2 at an annual rate of 6% in China (Chen *et al.* 2016). As a result of increased impervious urban surface area, rainfall is becoming surface runoff in a shorter time with a larger peak discharge (Jacobson 2011). Surface runoff can be collected by underground drainage systems, but when the system is overloaded beyond its design capacity and surcharges, stormwater overflows at junctions and results in surcharge-induced inundation of depressions. For many cities bordering a river, stormwater cannot be drained into the river without pumping stations because the hydraulic head of river is higher than that of the drainage outlets. Moreover, the Intergovernmental Panel on Climate Change (IPCC) has stated that extreme precipitation will increase significantly and could lead to more severe inundation in urban cities (Solomon *et al.* 2007). For example, when Typhoon Herb hit North and Central Taiwan in 1996, the maximum accumulated rainfall of 160 mm/hr and 1,748 mm/d caused casualties, a considerable amount of property damage and widespread destruction of basic infrastructure (Cheng & Wang 2004).

In recent years, escalating flood hazards have raised public awareness and increased fiscal expenditure on urban flood management infrastructure, such as additional pumping stations and drainage networks. However, precluding inundation through drainage system improvement is not always economically feasible in the current economic situation in China, or many other places in the world, and often, despite construction of extra flood control measures, stormwater inundation has still occurred when the drainage systems surcharge. In order for the government to be able to adopt measures to reduce property and casualty losses in advance, it is necessary to identify the potential location of inundation zones and their respective inundation depths when rainfall events occur. Such knowledge allows effective allocation of drainage system improvements and facilitates improvement of urban inundation forecasting and warning systems, which also play a major role in urban flood prevention (Chang *et al.* 2010).

Commercial software developers provide various urban inundation models, such as Mike Flood (D.H.I. 2012), InfoWorks ICM (Integrated Catchment Modeling) (Innovyze 2014), and XP-SWMM (Phillips *et al.* 2005) Furthermore, many studies have been carried out on urban stormwater inundation (Chen *et al.* 2005; Kang 2009; Yu *et al.* 2014).

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Hsu *et al.* (2000) presented an urban inundation model that combined the United States (US) Environmental Protection Agency (EPA) Storm Water Management Model (SWMM) and a two-dimensional (2D) overland-flow model and applied it to downtown Taipei. Seyoum *et al.* (2011) coupled a one-dimensional (1D) storm sewer model and a 2D noninertia overland-flow model to simulate urban flooding. This 2D surface model calculated inundation by solving 2D shallow water equations derived from applying physical laws to fluid motion, but was a complex and time-consuming process. In order to lessen this problem and reduce computation time, some methods like adaptive moving mesh (Zhou *et al.* 2013) and domain tracking method (Judi *et al.* 2011), which aimed to refine the numeric domain along with model running according to inundation propagation, were put forward. However, numeric domain simplification is only one solution to this problem. Calculating inundation information based on digital elevation model (DEM) or simplified hydraulic or hydrologic concepts is the other simplified method (Chen *et al.* 2009; Kang 2009; Leitão *et al.* 2013). This type of model does not involve any simulation of the physical process of inundation and is based on simplified hydraulic or hydrologic concepts. Teng *et al.* (2017) mentioned that this type of simplified model was orders of magnitude faster to run than models solving 2D shallow water equations, making them useful tools for large-scale applications where only final flood extent and water depths were required, dynamic effects being insignificant. Although the simplified models are time-saving, they have their own limitations. The modelled results are less accurate compared with the models that solve 2D shallow water equations. Chen *et al.* (2009) developed an urban flood inundation model where surface runoff was calculated by the Green-Ampt model and inundation was calculated by a geographic information system (GIS)-based method. In an effort to shorten computation time, they simplified both the surface model and the sewer model. Most importantly, they noted that coupling a real-world sewer system layout would produce more accurate results than a simplified sewer model, which tends to overestimate sewer conveyance during certain segments of storm events. Zhang & Pan (2014) presented an urban storm-inundation simulation method using the US Department of Agriculture (USDA) Soil Conservation Service method (McCuen 1982) to calculate surface runoff and using filling/spilling method to calculate inundation in GIS. They concluded that some errors might exist in inundation simulation due to the parameters of drainage capacity being simplified in the model.

In summary, most simplified models do not reflect the underground drainage system existing, which has an impact on inundation prediction, in adequate detail. In the present paper, the authors put forward a new model to simulate urban stormwater inundation that couples simulation of the true existing sewer system design with a surface diffusive overland-flow model. Furthermore, the newly proposed model will be calibrated and validated with a case study. Also, the paper will find out its advantages and disadvantages through comparison with another model.

URBAN INUNDATION MODEL

To simulate stormwater inundation in urban areas, the calculation process of the urban inundation model is divided into two models, namely the sewer flow model and the overland-flow model. For the former, SWMM is used to compute sewer flow in the underground sewer system and provides flooding flow at junctions. For the latter, the GIS-based diffusive overland-flow model is employed to calculate the detailed inundation regions and their depths resulting from the overflows on the overland surface.

Storm Water Management Model

In the present study, sewer flow in the underground drainage system is simulated through SWMM, which is developed by the US EPA. SWMM is a dynamic hydrologic-hydraulic water quality simulation model that is used worldwide for planning, analysis and design related to stormwater runoff (Rossman 2010). It conceptualizes a drainage system as a series of water and material flows between several major environmental compartments. These compartments include the atmosphere compartment, the land surface compartment, the groundwater compartment and the transport compartment.

In general, the channel and pipe flow routings are governed by the Saint-Venant equations (de St. Venant 1871). The Saint-Venant equations consist of mass conservation equation (Equation (1)) and momentum conservation equation (Equation (2)) for gradually varied, unsteady flow. In the transport compartment, SWMM solves the Saint-Venant equation using an explicit finite difference method and successive approximation.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \quad (1)$$

$$\frac{\partial h}{\partial x} + \frac{v}{g}\frac{\partial v}{\partial x} + \frac{1}{g}\frac{\partial v}{\partial t} = s_0 - s_f \quad (2)$$

where Q is discharge, A is area of flow cross section, h is depth of water, x is longitudinal distance, t denotes time, v is velocity, g is gravitational acceleration, s_0 is channel slope term and s_f is friction term.

GIS-based diffusive overland-flow model

The GIS-based diffusive overland-flow model is used to simulate surface flow and calculate surface inundation depths and extents. This model is developed in the C# language. The model requires a high-resolution DEM as the premise of accurate results. DEM is derived by applying an interpolation to scattered elevation points that were measured previously. Before interpolation, any incorrect elevation values were revised, including deletion of any incidental measurements of rooftops. The incorrect points are a minority of the total data set and therefore the deletions do not impact the accuracy of the DEM. Furthermore, buildings are regarded as nonflooding zones, and their elevations are raised to a predetermined baseline value to ensure they are not modeled as flooding. After these pre-processing steps, a DEM is interpolated at a resolution of 10 m using the inverse distance weighting interpolation method in ArcGIS. The DEM can then be applied in the GIS-based diffusive overland-flow model.

When SWMM finishes its calculations, the flooding water volume of each junction is updated in the database, which is then shared with the diffusive overland-flow model. Thus, the flooding volume is added as a property of each junction in the diffusive overland-flow model. In the diffusive overland-flow model, the study area is discretized onto a uniform grid with rectangular cells, which are arranged in a sequence of rows and columns. Each cell is regarded as storage that can store the flooding water. The land surface elevation of each cell is decided by the DEM. Then the flooding volume value of junction is set to be the flooding volume of cell in which it is located. Cells that do not overlay junctions or have junctions that are not overflowing are assigned a flooding volume value of 0.

The program transforms the flooding volume in each cell into flooding depth by dividing flooding volume by cell area. The cells in which flooding depth exceeds 0.05 m are defined as source cells. Unlike the traditional method in a flat-water model (Zerger 2002), which starts routing water from the lowest point (Chen *et al.* 2009), the source cells are set to be the starting points in the routing algorithm. The routing procedure is a loop and performs two steps in a single loop. During the first loop: (1) the routing algorithm allocates the flooding water of each source cell to its adjacent eight dry cells through a trial method if the topography allows. The model will firstly compute the total water depths, which in this model represent the water volume, in these nine cells and then reallocate the water to these nine cells in order to reach a same water level. Because the area of each cell is same, total water depths are the sum of the nine cell water depths. Figure 1 shows the procedures of allocating water in one loop. Figure 1(a) shows the source cell. After step 1, the water will diffuse to the adjacent eight cells if the topography allows (Figure 1(b)). (2) Step 2 is an inner loop. This loop starts when the first eight boundary cells produced. In each iterative step, boundary cells (i.e., cells one through eight in the first inner loop, cells one through 16 in the second inner loop) become the central cells and reallocate the water in each of their adjacent eight cells and themselves like the step 1 until the water depths in outermost boundary cells are less than 0.05 m. When the water depth of all boundary cells is below 0.05 m, the inner loop stops. After each inner iterative step, the scope of boundary cells will expand in a circle (Figure 1) if the topography allows. The

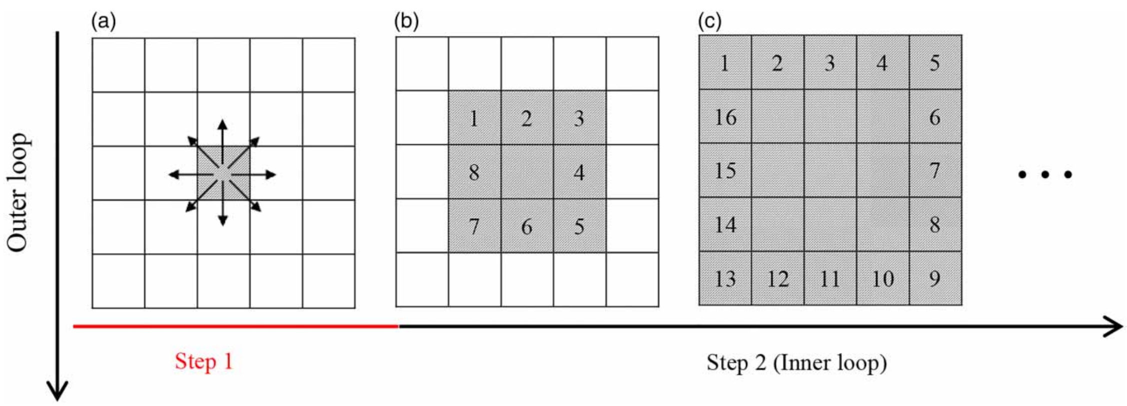

Figure 1 | Illustration of the diffusive procedure of the diffusive overland-flow model.

first outer loop ends here. Every outer loop starts from the source cells. When the outer loop of this model loops for a certain number of times, the water in the wet area will reach a flat water surface which is regarded as the final result. According to the final water level and elevations, the model can calculate the water depth for each cell.

The flow chart of the entire model process is depicted in Figure 2.

MODEL CALIBRATION AND VALIDATION

Case test

Located at the northern edge of the low-latitude tropics, Haikou, Hainan Province, China, has plenty of rivers, ponds, and swamps. Haidian Island, which makes up the northern part of Haikou, is a typical delta island with an area of 13.8 km^2 and is situated in the Nandu River estuary. Haidian Island contains the Wuxi Road open channel, Yawei River, and Baisha River. At the downstream estuary of the Wuxi Road open channel and Yawei River, there is a gate that plays an important role in flood protection and storm drainage operation.

In reality, rivers play an important role in the drainage system too, as surface runoff drains into them. Because the research region is urban area, the rivers are manual channels, of which the cross section is regular. Thus, rivers are set to be open channels in the model. There are 272 channels on Haidian Island which are set to be open channels in this study. In addition, when the underground drainage system severely surcharges, rainfall will flow to the land surfaces through junctions and drain at the next adjacent junction. In addition, there are eight lakes that are set to be eight storages in the model of Haidian Island. Finally, the model constructed for Haidian Island has a total of 2,677 junctions, 60 outfalls, eight storages and 2,690 pipes (Figure 3).

Subcatchments are regions in which SWMM calculates runoff produced by rainfall. Subcatchments of the Haidian Island study area are divided in ArcGIS according to the DEM and street distribution for a total of 2,915 subcatchments (Figure 3) with a size range of 0.048–25.94 ha. Since the Haidian Island terrain is relatively flat, more attention is paid to street distribution that divides the subcatchments. The slope of each subcatchment is calculated in ArcGIS, while the characteristic width of each subcatchment is calculated as the subcatchment area divided by the average maximum overland-flow length (Rossman 2010). The SWMM parameter Percent Impervious is calculated from a classification of impervious and pervious areas, distinguished by the software Environment for Visualizing Images (Envi 2010) (Figure 4). Other parameter values can be found in related published research (Rossman 2010; Krebs et al. 2014).

Haidian Island is surrounded by the sea with inhabited portions of island only ranging between 1 m and 2 m above sea level. Rainfall here drains into rivers through pipes and channels and eventually runs to the sea. Many streets are fully inundated when typhoons and storm surges occur.

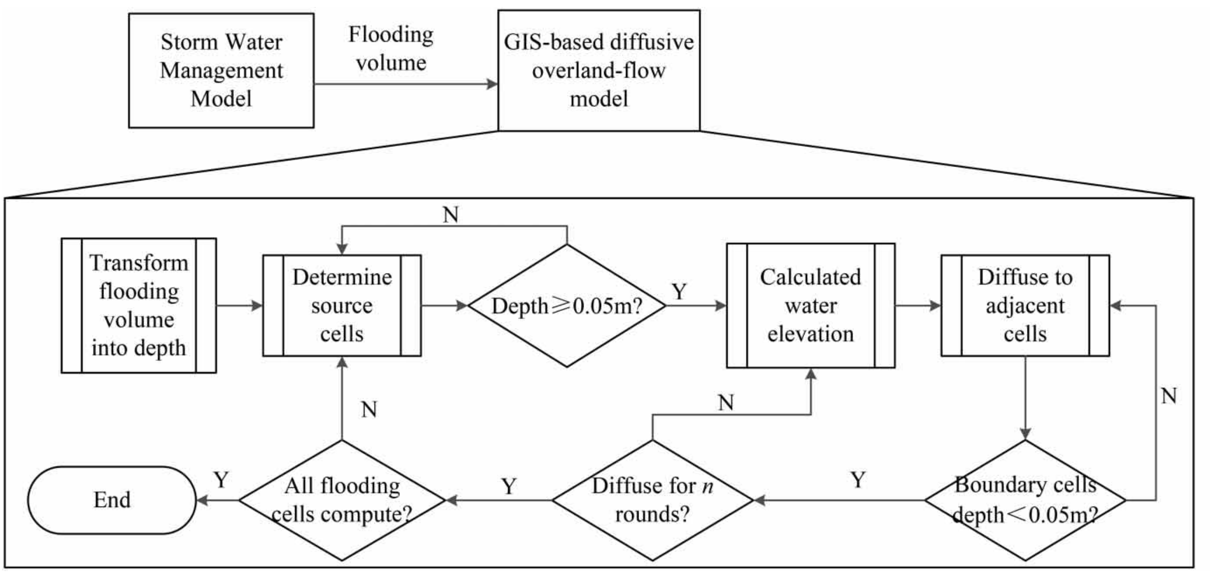

Figure 2 | Flow chart of model calculation.

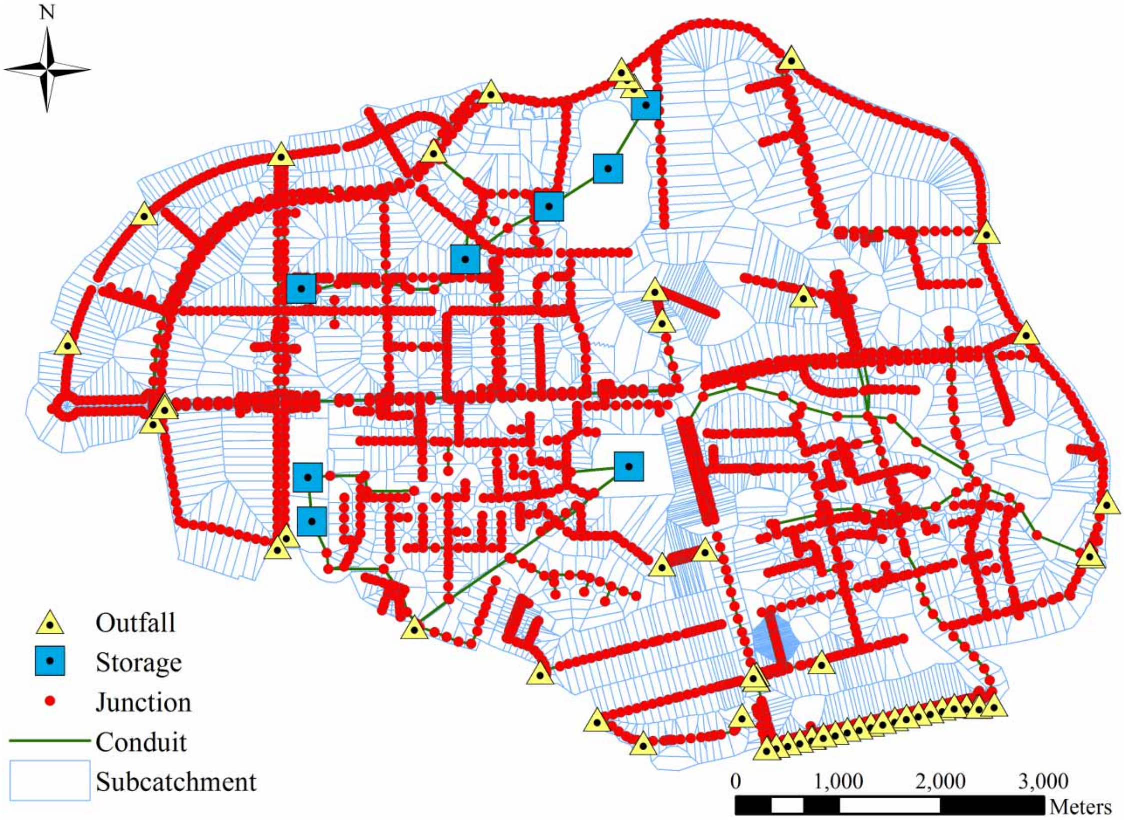

Figure 3 | Conceptual model of Haidian Island research region in Storm Water Management Model.

Figure 4 | Classification of impervious and pervious areas carried out using Environment for Visualizing Images software, where (a) is the remote sensing image and (b) is the classification result.

Since 2004, there have been 14 tropical cyclones that have caused disasters in Haikou. Rainfall from cyclones occurring on October 5, 2011, October 7, 2010, and October 13, 2008 caused severe losses. These three storms are referred to in the present study as storm 1, storm 2, and storm 3, respectively. Hyetographs of the three storms are plotted in Figure 5. Although many rainstorms have caused flooding, it is difficult to obtain field-surveyed inundation data. Fortunately, adequate field-surveyed inundation depth data were obtained for storm 1, storm 2, and storm 3 from the Haikou Drainage Management Bureau.

Calibration

Storm 1 was selected as the calibration scenario for stormwater inundation simulation of Haidian Island. It was recorded to cause severe inundation in many streets, including Wuxi Road, Renmin Road, Peace Avenue, Haida Road, with an average inundation depth of 0.5 m, resulting in traffic disruption and severe economic losses (Liang 2011). Figure 6 depicts the field-surveyed inundation extents in storm 1. Table 1 lists all parameter names and values for the Haidian Island subcatchments. These parameters are

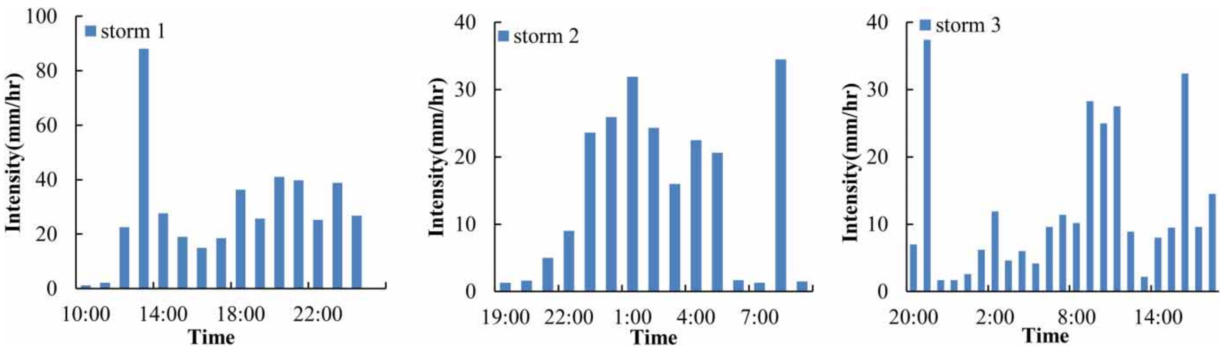

Figure 5 | Hyetographs of storm 1, storm 2, and storm 3.

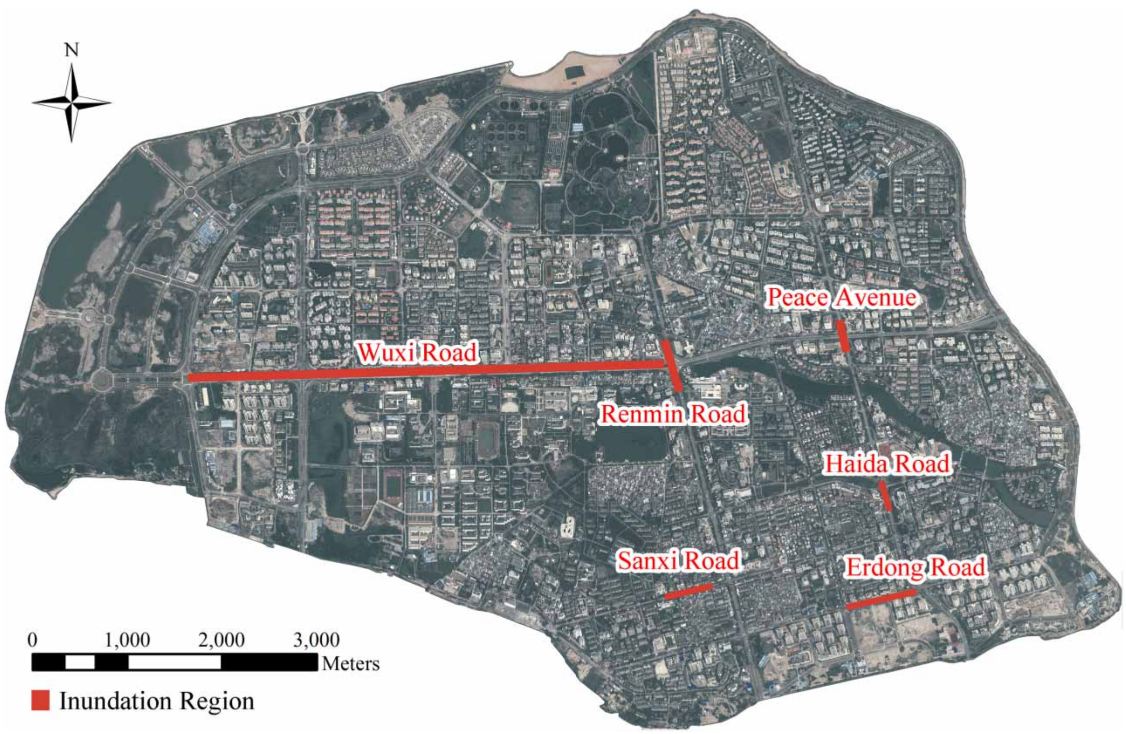

Figure 6 | Field-surveyed inundation extents for storm 1.

Table 1 | Parameter names and respective values for the Haidian Island study area subcatchments

Property	Definition	Value	Unit
N-Imperv	Manning's n for overland flow over the impervious portion of the subcatchment	0.015	$s/m^{1/3}$
N-Perv	Manning's n for overland flow over the pervious portion of the subcatchment	0.032	$s/m^{1/3}$
Destore-Imperv	Depth of depression storage on the impervious portion of the subcatchment	3.2	mm
Destore-Perv	Depth of depression storage on the pervious portion of the subcatchment	6	mm
%Zero-Imperv	Percent of the impervious area with no depression storage	20	%
MaxRate	Maximum infiltration rate on the Horton curve	82.5	mm hr^{-1}
MinRate	Minimum infiltration rate on the Horton curve	3.5	mm hr^{-1}
Decay	Infiltration rate decay constant for the Horton curve	3.13	1/hr

firstly decided by suggesting values in SWMM user's manual or relevant references and calibrate them by the field-surveyed inundation depths and extents. Meanwhile, a (calibrated) InfoWorks model was available and used for comparison.

Figure 7(a) and 7(b) depict the modeled inundation depths and extents in storm 1 with diffusive model and InfoWorks ICM. According to the comparison of Figure 7(a) and 7(b) with Figure 6, the modeled inundation extents are found to be in line with the field-surveyed inundation extents. Furthermore, Table 2 shows the calibration results. From Table 2, the maximum modeling inundation depths with diffusive model are very close to the field-surveyed inundation depths with a maximum absolute error (AE) of 0.15 m at Peace Avenue and a minimum AE of −0.04 m at Erdong Road. As for the InfoWorks ICM model, the maximum AE is 0.18 m at Sanxi Road and the minimum AE is −0.03 m at Renmin Road and Haida Road. The calibration results indicate that the modeled inundation situation was in accordance with the field-surveyed situation, which implies the reliability of the model parameters.

Validation

Storm 2 and storm 3 are regarded as the validation scenarios in this case test. The results modeled with InfoWorks ICM are perceived as comparisons with diffusive model. The model results with diffusive model and InfoWorks ICM of storm 2 and storm 3 are depicted in Figure 7(c)–7(f).

From Figure 7(c)–7(f), it can be found out that neither Peace Avenue nor Sanxi Road has inundation regions and others suffered from varying inundations. Both modeling inundation extents include not only the recorded inundation extents, but also the unrecorded ones. However, there are more inundation extents and the inundation depths vary in wider scopes in modeling results with InfoWorks ICM. The most important reason is that overland flows in InfoWorks ICM model can route to other regions under the premise of obeying the law of hydraulics, which exactly has the concept of flow instead of filling the depressions. Furthermore, from Figure 7(c)–7(f), we can find not only the inundation extents according to the recorded data, but also the inundation depths performing well.

More detailed inundation depths are depicted in Table 3 and Table 4. In Tables 3 and 4, AE1 represents the absolute errors between diffusive model results and recorded data and AE2 represents the absolute errors between diffusive model results and InfoWorks ICM results. Although the main inundation extents are successfully simulated by diffusive model and InfoWorks ICM model, there exist some differences in inundation depths through Tables 3 and 4. From Table 3, the maximum inundation depth difference between diffusive model and recorded data occurs in Renmin Road with an AE1 of −0.09 m, while the minimum AE1 is 0 in Wuxi Road and Sanxi Road. According to the AE1, diffusive model results in the recorded extents are close to recorded data. The maximum inundation depth difference between diffusive model and InfoWorks ICM also occurs in Renmin Road with an AE2 of −0.31 m, while the minimum difference, 0, is located in Sanxi Road. Haida Road is modeled to be no flooding with InfoWorks ICM. However, in the diffusive model results, there is 0.16 m inundation depth in Haida Road, which is closer to the recorded data, 0.2 m. As for Table 4, in storm 3, the maximum AE1 still occurs in Renmin Road, which is the same situation in AE2. Through comparing AE1 with AE2, diffusive model results are closer to the recorded data. Although there are some differences occurring in the

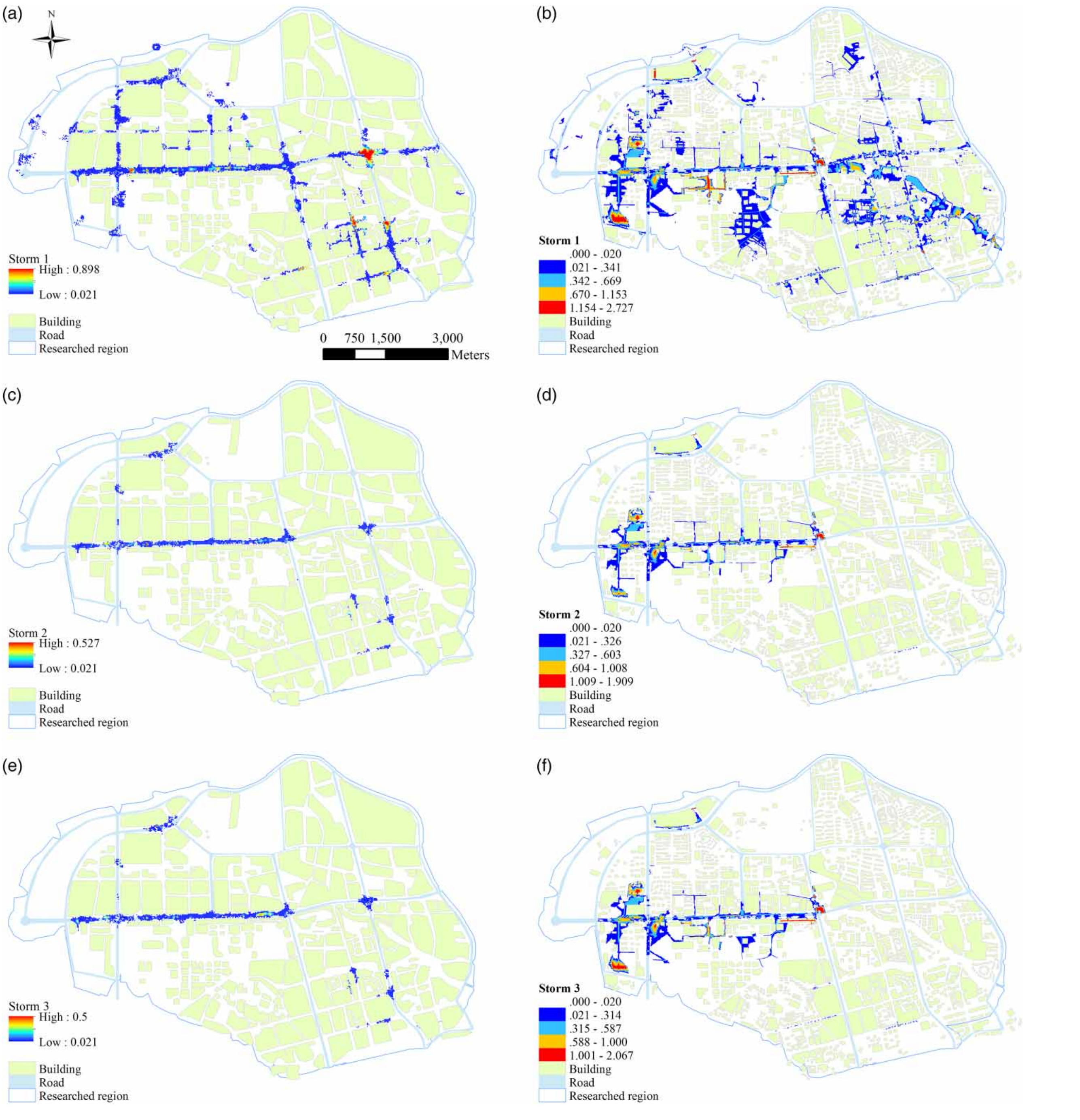

Figure 7 | Modeled inundation depths for storm 1, storm 2, and storm 3 ((a), (c), (e) for the diffusive overland model; (b), (d), (f) for the InfoWorks ICM (Integrated Catchment Modeling)).

simulated inundation depths in Haidian Island, it is a comfort to see that the inundation extents are predictable in such a large study area through diffusive overland model simulation. Thus, the diffusive overland model was considered as a relatively accurate model to simulate the inundations in Haidian Island.

DISCUSSION

Comparing the results from diffusive model and InfoWorks, some differences exist in inundation depths and inundation extents. These differences can be explained through comparing their computation theories. Diffusive model does not

Table 2 | Model results in storm 1 at Haidian Island

		Storm 1				
Inundation property	**Inundation extent**	**Recorded**	**Diffusive**	**AE (diffusive)**	**InfoWorks**	**AE (InfoWorks)**
Max. depth/m	Wuxi Road	0.5	0.61	0.11	0.62	0.12
Max. depth/m	Renmin Road	0.5	0.41	−0.09	0.47	−0.03
Max. depth/m	Haida Road	0.5	0.63	0.13	0.47	−0.03
Max. depth/m	Peace Avenue	0.5	0.65	0.15	0.54	0.04
Max. depth/m	Erdong Road	0.5	0.46	−0.04	0.55	0.05
Max. depth/m	Sanxi Road	0.4	0.48	0.08	0.58	0.18

AE means the absolute errors between model results and recorded data.

Table 3 | Model results in storm 2 at Haidian Island

		Storm 2				
Inundation property	**Inundation extent**	**Recorded**	**InfoWorks**	**Diffusive**	**AE1**	**AE2**
Max. depth/m	Wuxi Road	0.40	0.41	0.40	0	−0.01
Max. depth/m	Renmin Road	0.2	0.42	0.11	−0.09	−0.31
Max. depth/m	Haida Road	0.2	0	0.16	−0.04	0.16
Max. depth/m	Peace Avenue	0	0	0.05	0.05	0.05
Max. depth/m	Erdong Road	0.3	0.24	0.31	0.01	0.07
Max. depth/m	Sanxi Road	0	0	0	0	0

AE1 represents the absolute errors between diffusive model results and recorded data and AE2 represents the absolute errors between diffusive model results and InfoWorks ICM (Integrated Catchment Modeling) results.

Table 4 | Model results in storm 3 at Haidian Island

		Storm 3				
Inundation property	**Inundation extent**	**Recorded**	**InfoWorks**	**Diffusive**	**AE1**	**AE2**
Max. depth/m	Wuxi Road	0.4	0.43	0.45	0.05	0.02
Max. depth/m	Renmin Road	0.3	0.42	0.13	−0.17	−0.29
Max. depth/m	Haida Road	0.2	0	0.21	0.01	0.21
Max. depth/m	Peace Avenue	0	0	0.04	0.04	0.04
Max. depth/m	Erdong Road	0.3	0.30	0.30	0	0
Max. depth/m	Sanxi Road	0	0.19	0	0	−0.19

AE1 represents the absolute errors between diffusive model results and recorded data and AE2 represents the absolute errors between diffusive model results and InfoWorks ICM (Integrated Catchment Modeling) results.

consider the water exchange between surface flow and underground sewer flow, while InfoWorks ICM considers this exchange and calculates the exchange discharge through weir formula and orifice formula. This difference changes the whole underground pipe flow and results in different flooding water volumes and the number of flooding junctions. Flooding water volumes and the number of flooding junctions are shown in Table 5. From Table 5, the flooding water

Table 5 | Flooding volumes and number of flooding junctions in three storms

Results	**Model**	**Storm 1**	**Storm 2**	**Storm 3**
Flooding volume (m^3)	InfoWorks	369,505	102,740	130,297
	Diffusive	365,748	75,976	96,542
Number of flooding junctions	InfoWorks	1,060	376	431
	Diffusive	630	157	166

volumes from InfoWorks are a bit larger than those from diffusive model. The results from InfoWorks are composed of the maximum cell data during the whole simulation period. Thus, it is reasonable that the flooding water volumes of InfoWorks ICM are larger than those of diffusive model. As for the number of flooding junctions, they have the same law as flooding water volume. Furthermore, the spatial distribution of flooding junctions is depicted in Figure 8. From Figure 8, the flooding junctions of InfoWorks ICM are distributed in a wider range than those of diffusive model, which results in a wider range inundation extent of InfoWorks ICM. In this paper, the SWMM engine was chosen to calculate the sewer flow in InfoWorks ICM. Thus the flooding volumes and the number of flooding junctions obtained in 1D (SWMM) and 1D-2D (InfoWorks ICM) simulation are simply different because of the dynamic interaction between pipes and surface, which is not considered in the diffusive model. As a whole, the dynamic interaction between pipes and surface is the main cause of the differences existing in inundation depths and inundation extents.

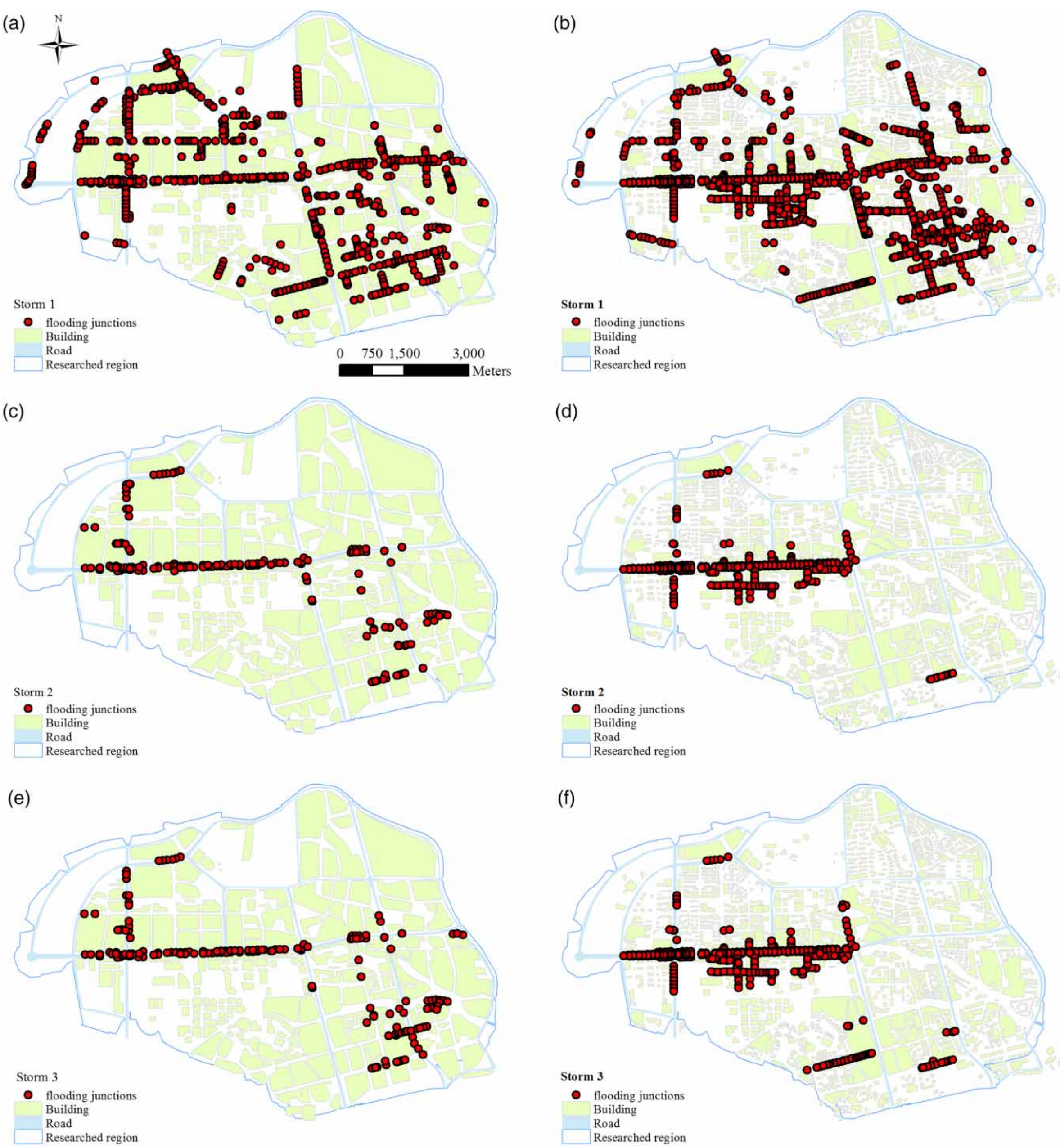

Figure 8 | Modeled flooding junctions for storm 1, storm 2, and storm 3 ((a), (c), (e) for the diffusive overland model; (b), (d), (f) for the InfoWorks ICM (Integrated Catchment Modeling)).

Furthermore, there exist some limitations in diffusive model that cause the differences between diffusive model and InfoWorks ICM or the recorded data. Firstly, the model simplifies some complex physical phenomena with two simple assumptions. For the first assumption, the flow of flooding water in diffusive model is simplified to be the filling of depressions, which strictly speaking does not represent the concept of flow. The water exchange between two adjacent cells on the surface is based on the topography instead of the law of hydraulics. For the second assumption, only the below-to-above flows are considered when calculating the exchange flows between above- and below-ground drainage system. But in reality, when the capacity of underground drainage system becomes available, the flooding water may flow into the drainage system from surface ground. Therefore this assumption may cause larger predicted flooding volumes than what is really observed. Secondly, apart from the simplification, lack of physical signification is the other limitation. Diffusive model has no representation of flow dynamics and cannot predict velocities.

Objectively speaking, there are two limitations that affect the application of this model. The first is the availability of data. Resolution and accuracy of topographic data, underground drainage data and historic inundation data are important to the accuracy of this model. The second is the topography of research regions. The considered case study area is a flat urban area, which benefits diffusive model which simply distributes water in sinks. The performance might look very different in catchments with a different topography. Because diffusive model has not been applied in the uneven urban area, it is hard to define its accuracy in the uneven area. Further research will focus on this point.

Even with noted limitations, there are some advantages existing in this modeling approach. Modeling the real-world underground drainage system instead of any other approximation approaches is the first advantage. The model can simulate the flooding flow more truly with coupling real-world underground drainage system calculation. The second is that the underground drainage system modeling considers the sea level as the boundary condition, which is a great difference from the other simplified model (Chen *et al.* 2009; Zhang & Pan 2014). Thirdly, models that calculate urban inundations through solving 2D shallow water equation are time-consuming. The diffusive model is a simplified model that can shorten calculation time, which is conducive to urban inundation forecasting and warning. Compared with InfoWorks ICM, the acceleration ratio of diffusive model is about 6, which means that the calculation speed of diffusive model is 6 times as quick as that of InfoWorks ICM. To be sure, it should be highlighted that this model can provide accurate inundation extents and reasonable inundation depth in large study area. Thus, there is no doubt that the model has utility worth in urban inundation forecasting and warning in spite of the limitations.

CONCLUSIONS

This paper proposed an urban inundation calculation model based on the SWMM and a GIS-based diffusive overland-flow model. In the model, SWMM is used to compute sewer flow and flooding overflows through junctions, while a surface diffusive overland-flow model is used to simulate overland flow on urban ground surface caused by drainage flooding.

The model was used to study the Haidian Island with a calibration scenario and two validation scenarios. Through comparing the model results with field-surveyed measurements and InfoWorks model results, the diffusive overland model appears to predict the inundation extents accurately and provides reasonable inundation depths. In addition, compared with InfoWorks model, diffusive model lacks hydraulic background and is a unidirectional model, while the advantage of this model is its efficiency. However, compared with the other simplified model, this model can take underground drainage system and boundary condition into consideration, which are impracticable in many simplified models.

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