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Urban flood simulation based on the SWMM model

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Abstract China is the nation with the fastest urbanization in the past decades which has caused serious urban flooding. Flood forecasting is regarded as one of the important flood mitigation methods, and is widely used in catchment flood mitigation, but is not widely used in urban flooding mitigation. This paper, employing the SWMM model, one of the widely used urban flood planning and management models, simulates the urban flooding of Dongguan City in the rapidly urbanized southern China. SWMM is first set up based on the DEM, digital map and underground pipeline network, then parameters are derived based on the properties of the subcatchment and the storm sewer conduits; the parameter sensitivity analysis shows the parameter robustness. The simulated results show that with the 1-year return period precipitation, the studied area will have no flooding, but for the 2-, 5-, 10- and 20-year return period precipitation, the studied area will be inundated. The results show the SWMM model is promising for urban flood forecasting, but as it has no surface runoff routing, the urban flooding could not be forecast precisely.

Key words urbanization; urban flood; SWMM model; design precipitation; inundation

INTRODUCTION

China is a nation with the fastest urbanization in the past decades, its urban population grew by over 50% in 2011 (Fang *et al.*, 2011), and is still steadily increasing. China's rapid urbanization has many impacts, including urban flooding. Due to rapid urbanization, urban flooding occurs more frequently and spreads from the coast cities to inland cities. For example, urban floods occurring in the Pearl River Delta Area cities in the past decades have caused serious casualties and property losses (Zhou *et al.*, 2013). Mitigation of urban flooding is becoming an important duty of the Chinese government.

Flood forecasting is one of the important flood mitigation methods, and is widely used in catchment flood mitigation (Zhang, 2002). Flood forecasting relies on flood forecasting models, and lots of flood forecasting models have been proposed, such as the Stanford model (Crawford *et al.*, 1966), the Xinanjiang model (Zhao, 1977), the ARNO model (Todini, 1996), the SHE model (Abbott *et al.*, 1986a,b), and the Liuxihe model (Chen *et al.*, 2011), among others. The models used in catchments cannot be used directly in urban areas as there is a high density of buildings and underground pipelines that are not treated by catchment models. There are urban hydrological models which can deal with underground pipeline flow and even surface runoff flow, and determine inundation conditions, such as ILLUDAS model (Terstriep *et al.*, 1974), SWMM model (Cole *et al.*, 1976), TR-55 model (USDA, 1986), Inforworks model (Koudelak *et al.*, 2008), and the STORM model (Wiles *et al.*, 2002). These models have been widely used in urban flood planning and management, but not used so much in urban flood forecasting.

This paper employs the SWMM model, one of the widely used urban flood planning and management models for simulating urban flooding of the rapidly urbanized Chinese city, to test if SWMM could be used for urban flood forecasting. The study was carried out in Dongguan City in southern China; the results shows the SWMM model is promising for urban flood forecasting.

DATA AND METHOD

Dongguan City in southern China is one of the fastest urbanized areas and has experienced serious flooding and losses of both human beings and properties. A highly urbanized area within Dongguan city, the Xinkaihe River drainage area is the study area. It is an independent drainage area with a high density of commercial and residential buildings and roads, and green fields in some places. The drainage area is 196.72 ha, with 106.71 ha impervious area that accounts for 54.24% of the total area. Figure 1(a) shows the land use map of the Xinkaihe River drainage area.

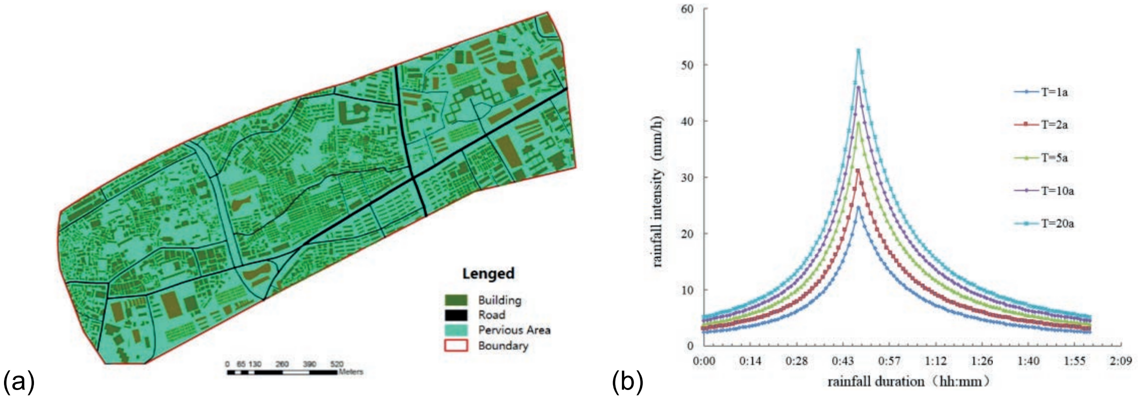

Fig. 1 (a) Land-use map of the Xinkaihe River drainage area; (b) Design precipitation of the studied area with five different return periods.

Data

Data collected for this study includes the underground pipeline data of the studied area, the DEM and digital map of the whole of Dongguan City. In the digital map, there are spatial information for roads, buildings, residential area, vegetation, river system, lakes, reservoirs, etc.

Precipitation is the driving factor for urban flood models and could be observed precipitation or design precipitation. A design precipitation for Dongguan City has been produced (Zhou *et al*., 2012), and in this study is used as the design precipitation of the study area for flood simulation. Figure 1(b) shows the design precipitation of the studied area with five different return periods: 1 year, 2 year, 5 year, 10 year and 20 year.

Method

SWMM, the EPA Storm Water Management Model (SWMM, http://www.epa.gov/athens/wwqtsc/html/swmm.html, visited on 2 October 2014) is a dynamic rainfall–runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. In SWMM, the whole study area is divided into subcatchments, and precipitation is averaged on the subcatchment. The surface runoff is produced on subcatchments also, and three methods can be used to produce the surface runoff. The surface runoff in a subcatchment is regarded to fully enter the junction related to it to be transported in the storm sewer conduits to the area outlet, so there is only pipeline runoff flow and no surface runoff routing is considered. SWMM was first developed in 1971 and has undergone several major upgrades since then. In this study, the latest edition, Version 5, is used for the model setting up and flood simulation.

MODEL SET-UP

Subcatchment division

To divide the subcatchment, 40 junctions were identified first based on the digital map and the pipeline network, the subcatchments were then delineated with the Thiessen polygons method which has the junction as its centre (Fig. 2(a)). With this division, the basic data of every subcatchment could be derived with the digital map, includingthe area, width, average slope, rate of impervious area, and is shown in Table 1.

Outline of the storm sewer conduits

Based on the collected data and location of the junctions, the pipeline network was outlined (Fig. 2(b)). The properties of the junctions and pipeline network were extracted, including the surface and bottom elevation, maximum water depth of the junctions, the length, the shape, the diameter and slope of the storm sewer conduits. The properties data of the junctions are shown in Table 2.

Table 1 Basic subcatchment data.

ID	Area (ha)	Width (m)	Average slope (%)	Rate of impervious area (%)	ID	Area (ha)	Width (m)	Average slope (%)	Rate of impervious area (%)
S0	13.65	402.68	1.49	63.59	S20	3.83	169.68	0.99	44.84
S1	9.21	377.05	1.77	51.49	S21	5.20	246.33	1.11	58.71
S2	1.63	80.95	1.76	50.08	S22	5.26	249.17	1.08	58.83
S3	1.78	91.62	1.41	64.99	S23	4.00	176.99	0.99	59.38
S4	3.59	160.02	1.81	63.99	S24	2.51	140.32	0.87	58.56
S5	6.87	306.26	1.66	56.21	S25	6.62	321.11	0.87	48.56
S6	4.48	203.99	1.14	53.14	S26	8.90	354.43	1.18	52.51
S7	3.16	185.24	1.09	56.76	S27	4.53	222.68	0.25	44.77
S8	1.73	144.57	1.37	47.20	S28	12.73	375.40	1.55	44.24
S9	2.35	113.98	0.64	53.92	S29	4.15	171.08	1.55	59.55
S10	2.78	138.51	1.45	49.95	S30	3.80	184.48	0.09	55.01
S11	3.24	280.89	1.06	51.76	S31	9.46	374.95	1.25	59.22
S12	3.38	207.68	0.48	60.33	S32	2.97	153.56	0.60	49.66
S13	3.75	230.57	0.63	63.27	S33	2.34	124.48	2.99	45.01
S14	2.50	150.34	1.16	53.69	S34	3.03	146.56	0.68	40.74
S15	4.12	210.08	0.35	60.47	S35	7.08	314.99	1.39	59.61
S16	2.85	162.32	1.43	56.41	S36	3.28	152.50	0.99	37.00
S17	8.17	375.21	1.37	58.63	S37	3.27	178.67	1.05	39.25
S18	10.09	401.43	1.49	56.98	S38	3.28	210.54	1.24	52.81
S19	5.05	233.66	1.01	52.34	S39	6.10	323.32	1.45	51.85

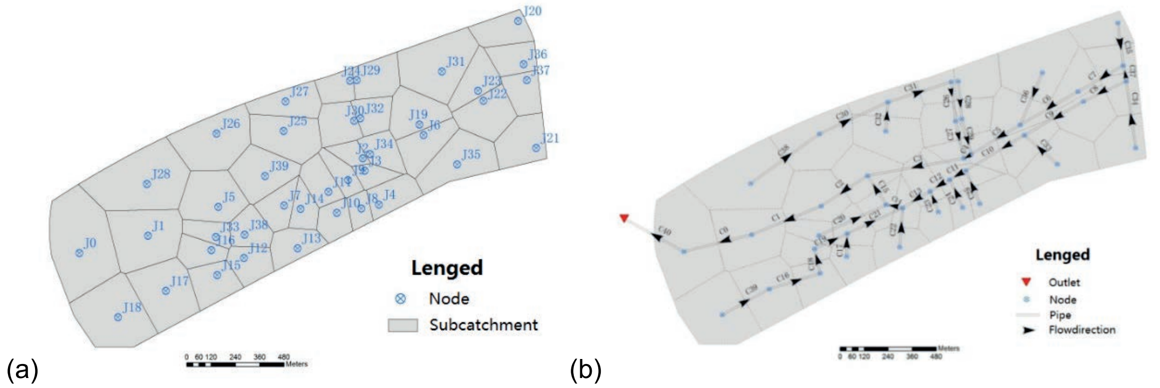

Fig. 2 (a) subcatchments division, and (b) outline of the storm sewer conduits.

Parameter determination

In this paper, the model parameters are derived based on the properties of the studied area according to the recommendations presented by SWMM model. To test the parameter's robustness, the parameter sensitivity analysis is carried out, and the results are shown in Fig. 3.

RESULTS AND DISCUSSION

With the model setting up above and the design precipitation, the flood processes with different return periods design precipitation have been simulated.

Simulated surface runoff

The simulated surface runoff, infiltration and precipitation are shown in Fig. 4. From the results it can been seen that with the increase of the return period, the total precipitation, surface runoff, runoff coefficient increase, but the infiltration does not increase obviously, this is because the studied area has a very high impervious area rate.

Table 2 Properties of the junctions.

Junction name	Surface elevation (m)	Bottom elevation (m)	Maximum water depth (m)	Junction name	Surface elevation (m)	Bottom elevation (m)	Maximum water depth (m)
J0	7.69	5.69	2.00	J20	11.50	9.50	2.00
J1	8.13	6.13	2.00	J21	11.81	9.81	2.00
J2	9.70	7.70	2.00	J22	10.92	8.92	2.00
J3	10.01	8.01	2.00	J23	10.69	8.69	2.00
J4	10.30	8.30	2.00	J24	10.32	8.32	2.00
J5	8.73	6.73	2.00	J25	11.12	9.12	2.00
J6	10.45	8.45	2.00	J26	11.38	9.38	2.00
J7	9.35	7.35	2.00	J27	10.89	8.89	2.00
J8	10.08	8.08	2.00	J28	12.06	10.06	2.00
J9	9.85	7.85	2.00	J29	10.32	8.32	2.00
J10	9.80	7.80	2.00	J30	10.05	8.05	2.00
J11	9.66	7.66	2.00	J31	10.62	8.62	2.00
J12	10.20	8.20	2.00	J32	10.02	8.02	2.00
J13	9.79	7.79	2.00	J33	9.83	7.83	2.00
J14	9.47	7.47	2.00	J34	9.77	7.77	2.00
J15	10.44	8.44	2.00	J35	10.71	8.71	2.00
J16	10.24	8.24	2.00	J36	11.16	9.16	2.00
J17	10.82	8.82	2.00	J37	11.30	9.30	2.00
J18	11.19	9.19	2.00	J38	9.99	7.99	2.00
J19	10.22	8.22	2.00	J39	9.12	7.12	2.00

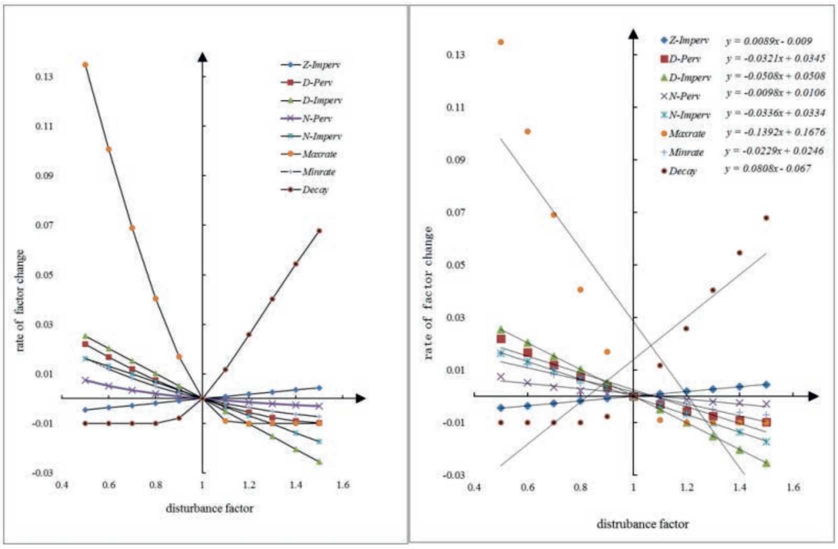

Fig. 3 Results of parameter sensitivity analysis.

Discharge at outlet

Both the discharge and water depth at the outlet are displayed in Fig. 5, but as results are simulated with the design precipitation, the results could not be validated, but the simulated hydrograph looks rather reasonable.

Simulated junction overflow

Junction overflow will cause inundation around the junction area, and is an important index for urban flood forecasting. From the results it was found that with the increase of the return period, the overflow junction number, the overflow volume and overflow duration increase steadily. When the return period is 1 year, there is no overflow, which means there is no urban flooding with 1

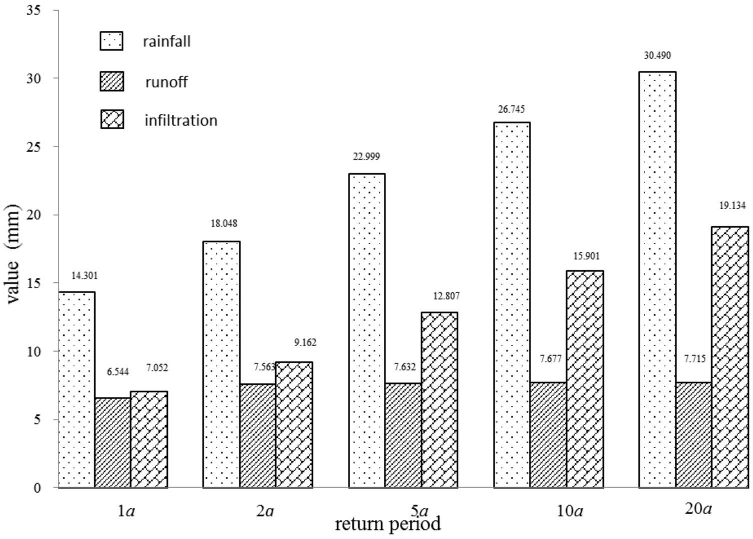

Fig. 4 Simulated surface runoff with different return periods design precipitation.

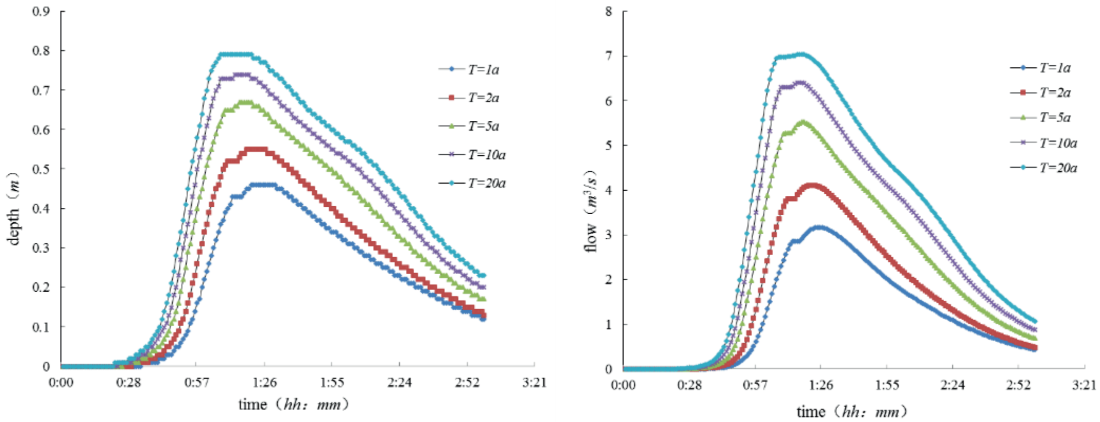

Fig. 5 Simulated discharge and water depth at the outlet.

return period year precipitation. But when the return period year is 2, 5, 10 and 20, the overflow junction numbers are 6, 22, 23 and 23, respectively.

Note that, as the SWMM model could not simulate the surface runoff directly, but by calculating the overflow water quantity to determine the inundation condition indirectly, the inundation index determined by SWMM is not so precise.

Pressured pipeline flow

Pressured pipeline flow is another index for urban flooding, if the pipeline is full of water, then it is pressured pipeline flow which means the neighbouring junction will overflow, and the pipeline may need to be enlarged. From the simulated results it was found that when the return period is 1 year, there is no pressured pipeline flow. When the return period year is 2, 5, 10 and 20, the storm sewer conduits with pressured pipeline flow are 9, 19, 20 and 20, respectively, and the storm sewer conduits with pressured pipeline flow for longer than 30 minutes are 2, 12, 18 and 19, respectively.

CONCLUSION

This paper, employing the SWMM model, one of the widely used urban flood planning and management models, simulated the urban flooding of the Dongguan City in the rapidly urbanized southern China. The SWMM model was set up based on the DEM, digital map and underground pipeline network, and parameters derived based on the properties of the subcatchment and the storm sewer conduits. The parameter sensitivity analysis shows the parameter robustness.

The urban flood processes were simulated with different return period design precipitation, and the results show that with the 1-year return period precipitation, the studied area will have no flooding, but for the 2, 5, 10 and 20 year return period precipitation, the studied area will be inundated. The results also show that the SWMM model is promising for urban flood forecasting, but as it has no surface runoff routing, the urban flooding could not be forecast precisely.

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