A Research of an Urban Rainstorm Water Model

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Abstract. Jinan city China has a special topography. It can be described as"south flood and north water logging"during the strong rainstorm events. In order to describe this characteristics, an urban rainstorm water model is constructed in this paper. This model can consider not only the inundation but also the street flood. The Lattice Boltzmann method is selected to calculate the hydrodynamic part of the model. Because of the Lattice Boltzmann method, the contradictions between numerical stability and computational efficiency of traditional numerical method is overcame, and the calculation efficiency is greatly improved. Through geographical information system (GIS), simulation results can be displayed in a visualized way. In order to test and verify the model accuracy, the observed data of Huang Taiqiao hydrological station on Xiaoqing River are used. The calculated results of the model are compared to the measured data, and the satisfactory simulation results are gained.

Keywords: urban rainstorm water model, Jinan City, the Lattice Boltzmann method, geographical information system.

1 Introduction

Since half-century ago, the urban flood disaster becomes more and more serious, hydrologist have to develop urban storm water models to study the mechanism of runoff and confluence in urban area. A lot of urban storm water models were established since 1960s in many countries such as United States, England, France and Germany. Among them, there are many famous models. For example: Storm Water Management Model, which is developed by United States Environmental Protection Agency in 1971[1,2]; Storage Treatment Overflow Runoff Model which is exploited by U.S. Army Crops of Engineers Hydrologic Engineering Center in 1977[3]; Walling Ford Model which is built by England environment and water resources committee in 1978[4]. In the past few decades, the function of urban storm water model is improved from single flood control to multifunctional water quality, environmental management and integrated decision support. The conception of model is developed from simple empirical model and conceptual model to complex physical model. And the range of application is extended from catchments area to the total city-wide. These trends of development lead to the urban storm water models are

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widely used in urban drainage and flood control works, and also obtaining good simulation results. But for some cities such as Jinan which have special topography, the existing models can not meet their requirements. Apart from the problem of water logging, Jinan has street lane flood which is caused by great gap of south-north elevation. It is difficult to describe by existing models. On the other hand, most of the physical models often use hydrodynamic method to solve surface water confluence. Some numerical methods, such as finite difference and finite volume, etc, are often used to solve these partial differential equations. However, there are contradictions between numerical stability and computational efficiency.

This paper aims to build an urban rainstorm water model according to the topographic feature of Jinan which can describe the flood response to rainfall events. In this model, the Lattice Boltzmann method is used to calculate the hydrodynamic part of the model. The computational efficiency can be improved significantly.

2 Study area description

Jinan is located in the Midwest of Shandong province. It is the capital of Shan dong province and an important administrative, commercial and industrial centre. The city has been developed a special topography between Mount Taishan and Yellow River. The elevation of south is much higher than north. For the main city zone of Jinan, a mountain is located on the south of it and there is a low-lying strip in the north. Jingyi Road is the boundary of gradient. The south of Jingyi Road is steep, and the gradient is 26‰～5‰ extend to north. The north of Jingyi Road is flat, the gradient is very small. However, due to the riverbed of Yellow River is higher than the main city zone of Jinan, a low-lying area in Beiyuan and Daming Lake is formed. Xiaoqing River becomes the only drainage outlet of Jinan. Because of the special topography, the southern mountain runoff and the rainfall of city itself will cause the flood to hit central city with large speed during strong rainstorm events. And because Xiaoqing River can not drain the flood in time, the low-lying area in north will inevitably be logged seriously. As a result, the situation of “south flood and north water logging” will be formed.

3 Model construction

In this paper, Jinan will be split into five parts by ArcGIS according to the characteristics of topography and digital elevation model (DEM) data. The five parts are: ① Southern Mountain in the south of Second Ring South Road with area of $70km^2$ ② the region which is in the west of Second Ring West Road plus the region in the north of Xiaoqing River, their area is $168km^2$. ③ the steep region which is from Beiyuan Road to Second Ring South Road, its area is $118km^2$ ④ the low-lying region which from Beiyuan Road to Xiaoqing River, its area is $15km^2$ ⑤ Xiaoqing River. The five parts are shown in the Fig. 1.

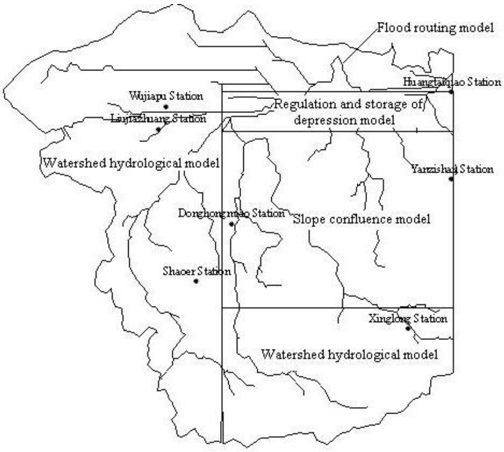


Fig. 1. The generalization of Jinan

Based on the generalization of Jinan, a rainstorm water model is developed as Fig. 2 suggest. The model consists of four sub-models. They are: watershed hydrological model, slope confluence model, regulation and storage of depression model, river flood routing model, respectively.

In this paper, Xinan Jiang (XAJ) model[5] is selected as watershed hydrological model in two regions. One is South Mountain, and the other one is the region which is in the west of Second Ring West Road plus the region in the north of Xiaoqing River. They are called southern XAJ model and western XAJ model in this paper. The runoff calculated by southern XAJ model drain to the slope confluence model. Kinematic wave equation is adopted as the mathematical equation, and the Lattice Boltzmann Method of D1Q3 three-speed model[6] is used as numerical method to solve this equation. Outflow which is calculated by slope confluence model and the rainfall on depression is regulated by the regulation and storage of depression model, its outflow is the lateral inflow of Xiaoqing River. The water from western XAJ model is the upper boundary inflow of Xiaoqing River. Flood routing based on diffusion wave equation is applied on Xiaoqing River, and the Lattice Boltzmann method is used to solve this equation[7].

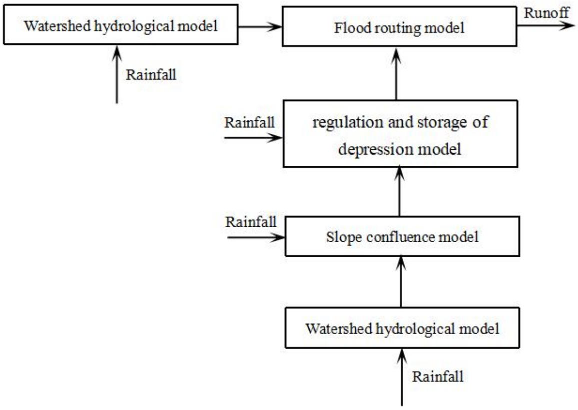


Fig. 2. The framework of Jinan urban rainstorm water model

4 Slope generalization

In the slope confluence model, the roads on slope are generalized according to the actual distribution of Jinan roads. The basic data of roads including length, width and gradient are given according to actual value. The roughness is adjusted as a parameter. The crisscross of south-north and east-west roads forms a road network which confluence characteristic is similar to river network. Because the gradients of south-north roads are significantly greater than the east-west roads, assumption that the flow of east-west roads is the lateral inflow of south-north roads is made. Therefore, east-west and south-north roads are encoded respectively.In addition, assuming that roads of south-north and east-west are the only confluence areas and other places are the runoff areas.

5 The visual display of model based on GIS

In this paper, the model depends on the function of spatial data analysis and visualization features of GIS, can display the simulation result in a visualized way. Through GIS the model can show the process of depth, velocity and flow on each node dynamically, and it can show the nodes which are easy to be submerged or the nodes which are in high velocity. The statistical analysis of node information can also be shown in this model.

In this simulation, the space step is 100m. Therefore, there is a node every other 100m, and a data series of depth, flow and velocity can be got. However, 140 nodes are selected as display nodes. Parts of them are junctions of roads, and others are dense points on the import roads. Both of them have strong representations. The distribution of nodes is shown in Fig. 3.

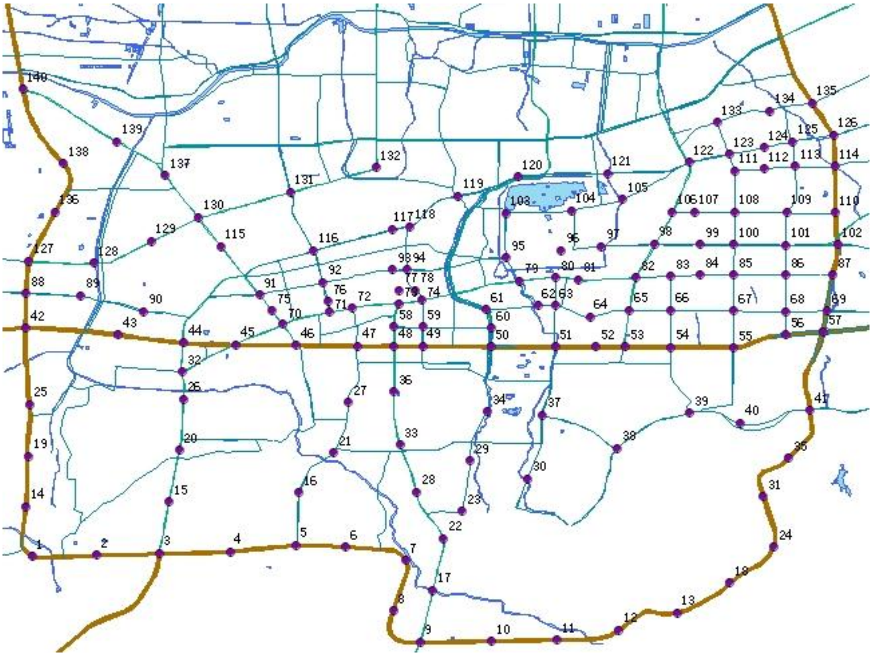


Fig. 3. The distribution of 140 nodes

The model is divided into two modules, they are calculation module and result display module. The calculation module is the core part of the model. It can calculate the water depth and current velocity of each node. And the outflow process of Huangtaiqiao Station can be got by the calculation process introduced above. The result display module has a lot of functions, they are dynamic display function, the display of submerged nodes function, current velocity function, results view function, results analysis function, early warning function and so on. Through these function module design, the water depth and current velocity of each node at different times can be viewed, the submerged nodes and the nodes of high current velocity can be counted. And the red, orange, yellow and blue warnings can be issued in the result display module[8].

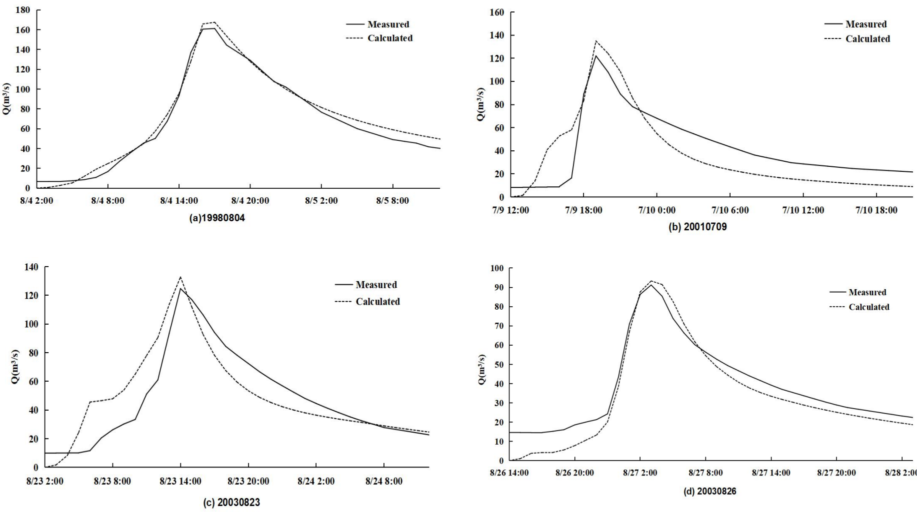
6 Model calibration and verification

There are not adequate observed data in urban area, especially the data of submerged area and flood depth, etc, in one rainstorm event. So it is difficult to test and verify the accuracy of most urban models. Huang Taiqiao hydrological station on Xiaoqing River is not only the control station of Xiaoqing River Basin but also is the only drainage outlet of Jinan City. So the observed data of Huang Taiqiao hydrological station will be used to test the accuracy of model which is constructed in this paper.

Table 1. The comparison between measured and calculated values

	Code of Flood	Runoff Depth(mm)		Peak Discharge(m^3/s)		Error of Relative Runoff Depth(%)	Error of Peak(%)	Deterministic Coefficient	Error of Peak Present
		Measured	Calculated	Measured	Calculated				
Parameter calibration	19980804	53	62.9	161.2	167.5	-18.75	-3.89	0.981	0
	20010709	37.4	25.1	122	134.9	32.83	-10.56	0.717	0
	20030823	37.4	32.4	124.7	132.7	13.31	-6.48	0.724	0
	20030826	28	25.3	91.2	93.3	9.51	-2.3	0.931	0
	20070718	62.3	68.7	198	197.3	-10.34	0.33	0.944	0
Parameter verification	19970819	43.6	36.1	147	118.1	17.1	19.68	0.917	+1
	19980810	56.1	53.9	184.7	163.2	3.98	11.59	0.9	0
	20030708	24.9	19.5	154	144	21.65	6.45	0.719	0

Parameters in this model are divided into three groups. They are the parameters of XAJ model, the parameters of slope confluence model and the parameters of flood routing model. Because the topography feature of southern mountain is greatly different from western region, so there are different runoff features between them. The parameters of southern XAJ model and western XAJ model will be debugged respectively. This paper selects five floods which are 19980804, 20010709, 20030823, 20030826, 20070718 for parameter calibration and three floods which are 19970819, 19980810, 20030708 for parameter verification. The calculated results by the model which is constructed in this paper are compared to the measured data of Huang Taiqiao hydrological station on Xiaoqing River in Table 1. The comparison between measured and calculated hydrograph in period of calibration and in period of verification are shown in Fig.4 and Fig.5 respectively.



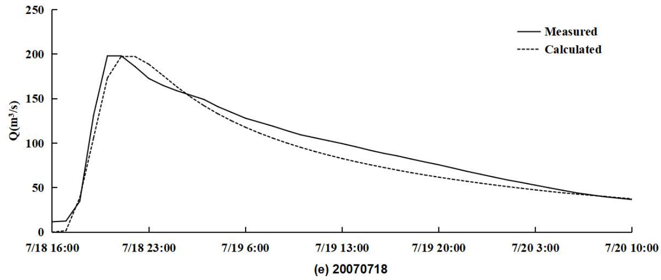
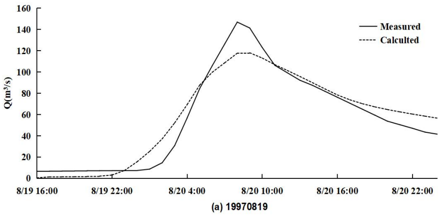
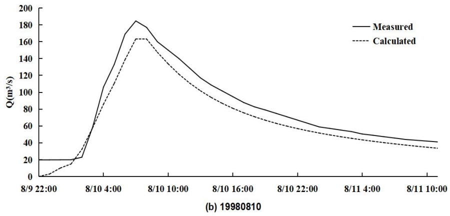


Fig. 4. The comparison between measured and calculated hydrograph in period of calibration





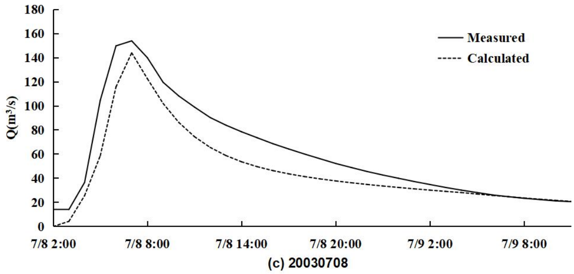


Fig. 5. The comparison between measured and calculated hydrograph in period of verification

Good fitting results were shown in these comparison figures.The urban rainstorm water model established in this paper has good accuracy. And it can reasonably reflect the phenomena of standing water and street flowing caused by rainstorm in Jinan urban area.

7 Conclusions

According to the characteristics of Jinan special topography, an urban rainstorm water model which consists of XAJ model, slope confluence model, regulation and storage of depression model, river flood routing model is constructed in this paper. This model achieved good simulation results. The model has many advantages. It can response the situation of "south flood and north water logging" in Jinan. It can improve the computational efficiency greatly by selecting the Lattice Boltzmann method. It can display the simulation result in a visualized way in GIS environment. However, there are some disadvantages in the model. First, the model only stays in the study of surface confluence, mechanism of runoff and pipe network confluence are not taken into account. Second, there are a lot of parameters in the model,there are only one hydrological station on the Xiaoqing River to control the parameters of the entire model, so it is difficult to calibrate the model parameters. The model could be further improved by overcoming these disadvantages in the future work.

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