Urban flood simulation based on distributed hydrological model: Tongzhou District, Beijing

Bo Zhang1,2,a, Xiangyi Ding1,2,b,*, Chuiyu Lu1,2,c and Jianhua1,2,d Wang

1 State Key Laboratory of Simulation and Regulation of the River Basin Water Cycle, China Institute of Water Resources and Hydropower Research (IWHR), 1 Yu-Yuan-Tan South Road, Beijing, China
2 Department of Water Resources, China Institute of Water Resources and Hydropower Research (IWHR), 1 Yu-Yuan-Tan South Road, Beijing, China
a 786493581@qq.com, b dingxy@iwhr.com, c 63711279@qq.com, d 2970934127@qq.com, * corresponding author

Abstract: Floods are one of the most destructive natural disasters in the world, especially in densely populated and economic areas. Tongzhou is an important satellite city of Beijing, which undertakes the important mission of alleviating Beijing's non-capital functions. Therefore, it is of great significance to study and analyze the flood process in Tongzhou. In this study, the distributed hydrological model WEP-L was used to construct a storm flood model in Tongzhou, and the flood process under different storm scenarios was studied and analyzed. The results show that under the once in 20 years rainstorm scenario, the precipitation in the study area increased by 92%, and the peak flow of Beiguan station increased by 171%; under the once in 20 years rainstorm scenario, the precipitation in the study area increased by 246%, and the peak flow at the Beiguan station increased by 430%; under the once-in-a-century rainstorm scenario, the precipitation in the study area increased by 297%, and the peak flow at the Beiguan station increased by 606%. This study can provide reference for the urban flood control planning of Tongzhou.

1. Introduction

Floods are one of the most serious natural disasters in the world, and the losses caused by floods in human gathering areas are especially huge [1-2]. In order to alleviate this kind of disaster, scholars from various countries have carried out a lot of useful explorations, including flood forecasting, control, risk management, and assessment [3-9]. The simulation of urban flooding is mainly divided into three stages: experience exploration stage, algorithm innovation stage and comprehensive integration stage. In the empirical exploration stage, the Horton runoff generation theory, unit line, Chicago flow process line and other classic hydrological theoretical methods have provided theoretical basis and key methods for urban flood simulation [10]. In 1971, Storm Water Management Model (SWMM) was proposed [11, 12], which realized the integrated simulation of three basic urban hydrological processes, including surface runoff, surface confluence, and pipe network confluence. SWMM is also the main tool for studying urban flooding.

However, with the continuous development of 3S technology (RS, GIS and GPS), it is possible to use distributed hydrological models for storm and flood research. Compared with the SWMM model, the distributed hydrological model has incomparable advantages in surface runoff generation and
confluence. However, there are relatively few cases of using distributed hydrological models to study urban floods. In this study, a distributed hydrological model, WEP-L, was used to construct a storm flood model in Tongzhou area, and the results of the model were calibrated and verified, and the accuracy of the model was within an acceptable range. Finally, the flood process in Tongzhou area is simulated under different rainstorm scenarios, in order to provide reference for the urban flood control planning in Tongzhou area.

2. Study area
Tongzhou is located in the southeastern suburbs of Beijing, at the northern end of the Beijing-Hangzhou Grand Canal. The east-west width is 36.5km, the north-south length is 48km, and the total area is 906km². Tongzhou has a continental monsoon climate, which is affected by the winter and summer monsoons, forming a climate characterized by dry and windy spring, hot and rainy summer, cold and dry winter. The annual average temperature is 11.3℃, and the annual average precipitation is about 620mm. The rainstorm season in Tongzhou is very concentrated, mainly from July to August during the flood season, with the most from late July to early August, and the torrential rain varies greatly from year to year.

Tongzhou belongs to the alluvial plains of Yongding River and Chaobai River. It is about 50km from the Taihang Mountains in the west, 50km from the Yanshan Mountains in the north, and 100km from the Bohai Bay in the southeast. The terrain in the study area is flat, with a slight slope from the northwest to the southeast. The elevation is between 28.5m and 8.2m, and the ground slope is 0.3‰ to 0.6‰. The rivers in the study area belong to the Beiyun River and Chaobai River systems in the Haihe River Basin. Among them: the basin area of the Beiyun River system is 791km², accounting for 87%, and the basin area of the Chaobai River system is 115km², accounting for 13%.

3. Method and Model

3.1. Model principle
The development of the WEP (Water and Energy Transfer Process) model began in 1995. It has been improved and perfected from 1999 to 2002, and gradually matured. It has been verified and applied in many river basins in Japan and South Korea. Obtained the Japanese copyright registration [13]. From 2003 to 2004, on the basis of the original WEP model, a large-scale watershed distributed hydrological model WEP-L [14] was developed that coupled the natural water cycle process and the artificial collateral water cycle process. The slope confluence calculation in WEP-L uses the one-dimensional kinematic wave method to calculate the slope runoff from the upstream to the downstream of the basin based on the elevation, slope and Manning roughness coefficient of each contour zone. The confluence calculation of each river is calculated from upstream to downstream by one-dimensional kinematic wave method or dynamic wave method according to the presence or absence of downstream boundary conditions.

In the simulation of the various elements of the water cycle, canopy interception evaporation, soil evaporation, water surface evaporation, and vegetation transpiration are calculated according to the soil-vegetation-atmosphere flux exchange method (SVATS), using the Noilhan-Planton model, Penman formula and Penman-Monteith formula. Surface runoff can be divided into two types of runoff generation models: infiltration excess and saturation excess. The Green-Ampt model and Richards equation are used to calculate the soil flow in the soil layer of the slope. The movement of shallow groundwater was calculated in two dimensions, and it was dynamically coupled with unsaturated soil water and river water.

3.2. Model Construction
The basic data required for model construction include hydrometeorological, physical geography, socioeconomic data and other datas. As shown in Figures 1 and Figures 2, the soil type of the study area, and land use in 2005 and 2014.
As shown in Figure 3, the simulated river network of the study area was extracted based on the DEM data. The study area is divided into 736 sub-watersheds with an average area of 29.3 km².
3.3. Model Calibration
Based on the measured flood process data corresponding to the selected rainfall station, the 13 storm flood processes simulated based on the WEP-L model were calibrated, as shown in Figure 4. The results show that the Nash efficiency coefficient of the model is 0.70, the relative error between the simulated flood volume and the measured flood volume is 15.2%, and the model accuracy is within an acceptable range, which can be used to simulate the storm flood process in the study area.

4. Results and Conclusions
Through frequency calculation of the series of rainfall station data in the study area, the rainstorm process under different frequencies in Tongzhou can be obtained. The WEP-L model is used to simulate the peak flow process of Beiguan station (Fig.3) under the rainstorm in Tongzhou once in 20 years, as shown in Figure 5.

It can be seen that the precipitation in the study area increased from 138mm to 265mm, an increase of 92%, and the peak discharge of Beiguan station increased from 535.7m$^3$/s to 1450m$^3$/s, an increase of 171%.
The peak flow process of Beiguan under the rainstorm in Tongzhou once in 50 years is shown in Figure 6. It can be seen that the precipitation in the study area increased from 138 mm to 340 mm, an increase of 246%, and the peak discharge of Beiguan station increased from 535.7 m$^3$/s to 2306 m$^3$/s, an increase of 430%.

The peak flow process of Beiguan under the rainstorm in Tongzhou once-in-a-century is shown in Figure 7. It can be seen that the precipitation in the study area increased from 138 mm to 410 mm, an increase of 297%, and the peak discharge of Beiguan station increased from 535.7 m$^3$/s to 3246 m$^3$/s, an increase of 606%.

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