A Survey of Urban Waterlogging Algorithm Model

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Abstract

The improvement of urbanization has directly changed the formation conditions of urban rainstorm runoff, greatly changed its rainwater and flood movement characteristics, and the problem of urban flood control and drainage is becoming more and more serious. In order to prevent floods and minimize the losses caused by floods, the research on urban flood and ponding is particularly important. The urban waterlogging algorithm model generally simulates the urban street pavement, underground drainage pipe network and the movement of river flow, and establishes the rainstorm waterlogging and ponding mathematical model. Starting from the research status of waterlogging algorithm model, this paper introduced the basic properties of several common models such as SWMM, MIKE and InfoWorks, and briefly described the application of each model. This paper summarized the bottleneck problems existing in the research of mathematical models, and pointed out that multi-source information and model generalization are the future research directions.

Keywords

Urban Waterlogging, SWMM, MIKE, InfoWorks.

1. Introduction

In recent years, due to the excessive exploitation of the environment by human beings, abnormal climate change has led to the change of water cycle. With the accelerated development of urbanization, the quality problem of urban water conservancy construction is becoming increasingly prominent. In July 2021, Zhengzhou, Henan province, experienced several days of torrential rain, from reservoir emergency to Yellow River warning and flash flood, and the city’s drainage pipeline network was not enough to discharge a large amount of flood water in a short time. In order to reduce the risk of flood and waterlogging to the greatest extent and protect the safety of people’s life and property, climate prediction and urban water conservancy work should be done well, so it is very necessary to design a good urban water logging model.

2. Model

2.1 SWMM Model

SWMM(Storm Water Management Model) is a dynamic precipitation-runoff simulation model[1]. Jointly developed by EPA and Canadian Hydraulic Computing Centre (CHI), it has strong simulation calculation function for urban drainage system. SWMM is mainly composed of four computing modules, including runoff module, conveying module, expansion conveying module and storage processing module, and analysis and mapping service module [2]. It can make the analysis, design and optimization management of urban drainage system, optimization of storage capacity, storm water treatment analysis, flood area management, flood control and disaster reduction measures. It is mainly used to simulate a single precipitation event or long-term water and water quality simulation in the city [3].

2.1.1.Characteristics of Hydrological Model

SWMM can be used to deal with a variety of hydrological processes generated by urban regional runoff, including time-varying precipitation, precipitation interception by depressions, groundwater recharge by precipitation infiltration, surface evaporation and water exchange between groundwater and drainage pipes[4].

2.1.2.Characteristics of Hydraulic Model

The SWMM model has a set of flexible hydraulics modules to simulate the flow process of water in pipes, channels, and treatment units as well as water distribution structures in drainage pipes. It can simulate some special parts such as storage and treatment unit, diversion valve, weir and drainage orifice, water pump, etc. It can simulate various forms of water flow and deal with drainage network without size limitation, and simulate water flow in closed pipe and open channel pipe of various shapes[5].

2.1.3.Characteristics of Water Quality Model

Model can simulate the process of runoff pollution load. The user can select any number of water quality to simulate the project. Including the reduction of pollutants due to the street cleaning in the sunny days, the erosion of certain land pollutants by heavy rains, the pollutants in rainfall sediments, calculation of water quality items in drainage pipe network and other water projects[6].

2.2 MIKE Model

MIKE, which series software developed by Danish Institute of Water resources and Water Environment is a commercial flood simulation software widely used in the world. It integrates rainfall, runoff, groundwater, rivers, lakes, oceans, water pollutants and biological simulation functions. It has a broad prospect of application in hydrology and water resources, water environment protection, water conservancy project planning and design [7]. It includes: MIKE HYDRO (Watershed water resources Analysis model), MIKE 11 (one-dimensional model), MIKE 21 (two-dimensional surface overflow model), MIKE SHE (hydrology and groundwater model), MIKE URBAN (one-dimensional drainage network model), MIKE 3 (3D model), FEFLOW (groundwater model), WEST (sewage treatment model) and MIKE FLOOD (coupling model), et al.[8]. Among them, MIKE 11 model, MIKE 21 model and MIKE URBAN model are most commonly used. The following is a brief introduction of these three models.

2.2.1.MIKE 11 Model

MIKE 11 model is a hydraulic model based on the mass and momentum conservation of the Saint Venant equation and taking water level and flow as the research object[9,10]. The expression is as follows:

The continuity equation:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q$$

The momentum equation:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\alpha\frac{Q^2}{A}\right)+gA\left(\frac{\partial y}{\partial x}\right)+gAS_f-u\cdot q=0$$

Wherein, Q represents the flow volume through the water section, m3/s; t represents the time, s, A represents the channel water area, m2; u represents the velocity of lateral flow in the direction of the river, m/s; x represents the horizontal coordinate along the direction of water flow, m; q represents the lateral inflow of the river, m3/s; α represents momentum correction coefficient; g is the acceleration of gravity, m/s2; y represents the water level, m; Sf stands for the drag slope, which is expressed by Manning formula as follows:

$$S_f=\frac{Q|Q|}{K^2}=\frac{n^2u|u|}{R^{\frac{4}{3}}}$$

2.2.2.MIKE 21 Model

MIKE 21 model is a planar two-dimensional free surface model based on structured rectangular grid MIKE 21, unstructured grid MIKE 21 FM and orthogonal curved line grid MIKE 21C. The MIKE 21 modeling system based on MIKE provides an efficient design environment for engineering application and coastal management and planning. With the combination of the advanced graphical user interface and efficient computing engine it has become an indispensable tool for professional estuarine and coastal engineering technicians in the world[11].

Because the water depth is relatively shallower than the surface in MIKE 21, parameters such as water depth, flow velocity distribution in vertical direction can be approximate average processed. The governing equation of MIKE 21 can be obtained as follows:

$$\frac{\partial\xi}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t}$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial\xi}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2\times h^2}-\frac{1}{\rho w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}+\frac{\partial}{\partial y}h\tau_{xy}\right)\right]-\Omega_q-fVV_x+\frac{h}{\rho w}\frac{\partial}{\partial x}(p_a)=0$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial\xi}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2\times h^2}-\frac{1}{\rho w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}+\frac{\partial}{\partial x}h\tau_{xy}\right)\right]-\Omega_p-fVV_y+\frac{h}{\rho w}\frac{\partial}{\partial y}(p_a)=0$$

Where, h represents water depth; P and Q represent the flux in the x and y directions respectively. C stands for Chezy coefficient; G is the acceleration of gravity; Ω is Coriolis force coefficient; ρ is the density of water; V, Vx and Vy represent wind speed and its components in x and y directions; F is wind resistance coefficient; τxx, τxy and τyy are the effective shear force components[12].

2.2.3.MIKE URBAN Model

MIKE URBAN model is a model used to simulate surface runoff and drainage pipe network, which is divided into rainfall runoff module and storm pipe channel module [13].

There are linear reservoir model, T-S (time-area) curve model, unit hydrological process line, moving wave model and other model types in rainfall and runoff module [14]. Mouse RD II model can simulate precipitation and runoff for a long time, and divide rainwater into snow cover, root storage, groundwater and surface runoff, On this basis, a complete terrestrial hydrological cycle is constructed. The MIKE URBAN model is used to simulate the rainfall situation. The simulation results such as total runoff, runoff process and runoff peak value are fed into the storm sewer system as boundary input conditions.

The stormwater channel module is established by the one-dimensional Saint Venant equation and Abbott-ionescu six-point implicit finite difference scheme was used to solve the numerical solution, so as to obtain the flow situation in the storm sewer system [15]. It uses the pressure flow and free water surface similar to the circular and tree-shaped pipe network in the city, and it can smoothly transition the sudden change of flow, and it can simulate the situation that backwater top support and full pipe backfill very well. At the same time, the time step can be automatically matched according to the specified rules, which can meet the requirements of the model for calculation accuracy and speed.

2.2.4.Model Coupling Calculation

MIKE series software includes MIKE FLOOD model, which is specially designed for the coupling of one-dimensional and two-dimensional models among MIKE 11, MIKE URBAN and MIKE 21. The calculation results of the current step size of each model in the specified coupling step size are exchanged as the input of the next step. The coupling of one-dimensional model and two-dimensional model draws on each other's strengths and weaknesses to a certain extent. At the same time, it takes into account the advantages of accurate calculation and fast calculation of one-dimensional model and wide calculation range and strong display power of two-dimensional model, avoiding the problems of accuracy and data interaction when used independently.

MIKE FLOOD contains seven connections. Standard Link, Zero Flow Link, Lateral Link, Structure Link and Side Structure Link are used for coupling between MIKE 11 and MIKE 21. River-Urban Link is used for coupling between MIKE 11 and MIKE Urban. Urban Link is used for coupling between MIKE Urban and MIKE 21 [16,17].

2.3 InfoWorks Model

InfoWorks ICM (Integrated Catchment Model) is a software developed by HR Wallingford, which can combine many model engines and functions in a single simulation engine. In an independent simulation engine, ICM completely combines the one-dimensional water conservancy model of urban drainage pipe network and river with the two-dimensional flood and submergence model of urban drainage basin, realizing the integration of urban drainage pipe network system model and river model [18].

The system is composed of a one-dimensional urban drainage pipe network hydraulic model, the one-dimensional river systems hydraulic model and the two-dimensional city&flooded river basin flood model. It mainly used in the surface water management planning, sustainable drainage system planning, the flooding solution development, the urban rainfall runoff and river closure design and flood control planning and management and so on many areas [18].

3. Application Status

3.1 Application of SWMM Model

Based on the digital elevation model, Xue Fengchang used the modeling function of SWMM model to establish the modeling of urban drainage pipes, and established the simulation model of rainstorm accumulation and waterlogging in Hangzhou in combination with the data of urban topography and land use. He simulated the surface water depth and spatial distribution of urban waterlogging in Hangzhou under 8 kinds of rainfall during the reoccurrence period, and He performs parameter calibration and model validation. The technical method of numerical simulation of urban waterlogging under the perspective of rainfall risk is studied, and the comparison between the statistical results and the simulation results proves the rationality and reliability of the proposed urban rainstorm waterlogging simulation mapping method. Li Peng [20] coupled SWMM one-dimensional pipe network model and LISFLOOD-FP two-dimensional hydrodynamic model to simulate rainstorm waterlogging in Huangtaiqiao Watershed of Jinan city, and calibrated and verified the model based on measured precipitation, flow and inundation. The simulation results show that when the precipitation return period increases gradually, the overflow nodes in the study area increase the most, and the main streets are inundated to varying degrees. When the return period increases to 5a, there is serious waterlogging in the study area, indicating that there is a certain lag phenomenon in the drainage capacity of the study area.

Xu Huijun [21] proposed an urban stormwater simulation data modeling method that comprehensively considered the effects of surface open channels and pipe networks in view of the composite terrain characteristics of the Xianlin Campus of Nanjing Normal University. He combined the monitoring data of typical precipitation and simulated typical precipitation based on SWMM model, And he calibrated parameters with runoff coefficient as calibration target. His modeling method builds an automatic identification method for pipe network flow, and auxiliary implements the correct division of urban rain flood simulation seed catchment area. It can better simulate precipitation rain flood process in the study area. It can be practical application in city underlying surface or natural slope and artificial building comprehensive coverage of the area, and make actual precipitation into a scene simulation waterlogging. Wang Jingjing [22] constructed SWMM model for the main urban area of Jinan city. With the help of base flow horizontal segmentation method, He determined the required traffic data and applied flow data before and after segmentation to model calibration and validation Six different historical rainstorm flood processes were simulated, and the simulation effects before and after base flow segmentation were quantitatively evaluated. Research results show that the simulation precision is improved obviously. The simulation accuracy of the heavy rain events is increased by 43.7% on average and the relative error of the peak flow by 3.59%. It has no obvious influence on flood process fluctuation characteristics, such as peak and appearance time error and expand the base flow separation in the application of urban rain flood simulation. It provides some scientific basis and technical support for urban rainstorm flood disaster warning.

3.2 Application of MIKE Model

Zhao Yue [23] used MIKE Flood models coupled by MIKE Urban and MIKE 21 to study two-dimensional surface water in the study area to discuss whether the drainage capacity of the regional pipe network meets the standard and whether the surface water situation causes harm based on the current conditions in the research area, and predict the occurrence of waterlogging and propose solutions. Fu Chun [24] used MIKE Flood model to simulate the waterlogging and inundation state of Yuehu New Area in Yingtan City during rainfall and studied the complete process of urban waterlogging formation and recovery under rainfall in different periods. Based on the simulation results, he made statistics on the changes of inundated grids in the study area after rainfall in each return period. Based on the system performance, he analyzed and studied the elasticity of waterlogging in Yuehu New Area of Yingtan City, He further analyzed the defense and recovery ability of the study area against rainfall disasters in each recurrence period.

Wang Xianning [25] takes Malanzi drainage district of Dalian city as the research area and uses DHI-Mike series software to build a two-dimensional dynamic coupling model between underground drainage pipe network and urban surface. He sets up two rainstorm scenarios, one within standard and the other beyond standard and simulates the urban water waterlogging process under two schemes and make a comparative analysis of the pipeline carrying state and the change of waterlogging risk in the study area. He calculated the average submerged depth and volume of water for both scenarios and gave reasonable suggestions for defense measures. Wang Huaizhi [26] calculated the flood of river embankment breach by building MIKE 11 model and imported the results into MIKE 21 model to simulate the flood evolution after the occurrence of breach and obtain the inundation area, arrival time and other characteristics of flood. Taking the dangerous section of the main stream of Nanfeihe River in Hefei as an example, the application results show that the model can well simulate the breach flood and its evolution process caused by the super-standard flood, which provides technical support for the preparation of the super-standard flood plan.

Based on the MIKE FLOOD platform, Zhang Yixin [27] coupled MIKE 11 and MIKE 21 and MIKE URBAN to build the coupling model waterlogging. The rationality of the model is verified by the pipeline flow self-inspection method, and the simulation results are in good agreement with the actual situation. The results show that in the case of heavy rainfall, there are multiple overflow points in the study area. Different degrees of water accumulation on roads, and some pipelines are in the state of pressure flow. Most of the inspection wells overflow, which can not meet the demand of drainage. Aiming at the existing problem of flood control and drainage in the study area, waterlogging control scheme is put forward, which is based on the MIKE FLOOD. It realized the low impact development (LID) combination of measures setting and reduced the surface inundation area. The water depth is generally lower and the water point in time delay and water total duration of water is reduced. The drain pipe flow peak decrease obviously, Peak discharge of drainage is delayed. It provides technical support for disaster prevention and mitigation in the park and also provides reference for the construction of similar urban areas. Charlie [28] constructed the integrated flood calculation model of MIKE 11, MIKE 21 and MIKE FLOOD to simulate the flood inundated situation after the collapse of the dangerous section in the urban area. Based on the one-dimensional model, the virtual river channel was established, the one-dimensional hydrodynamic model and the two-dimensional hydrodynamic model were coupled in the way of lateral connection, and the breach was generalized by the control building module to simulate the flood evolution process from the breach to the urban area. According to the results of the study, it is of great guiding significance to divide the flood risk level of urban areas and plan the reasonable safe haven area and safe haven route. It has important guiding significance for urban flood control and disaster relief.

Zhang Xu [29] constructed the pipe network model and surface overflow model of the sponge city core pilot area of Fengxi New City. He coupled with MIKE FLOOD to measure data such as pipeline flow process and water depth of waterlogging point were used to calibrate and verify the model and the model results fit well with measured values. The model shows good applicability in the analysis and application of urban waterlogging and sponge city construction. Luan Zhenyu [30], based on the MIKE FLOOD platform, coupled with MIKE URBAN and MIKE 21 models to establish an urban waterlogging model, and simulated the drainage scenario of typical areas in Xinhua County, Hunan Province. The research results showed that the model constructed by the research could reflect the drainage pattern in urban areas in the performance of pipes and possible surface water. The simulation ability of traditional urban drainage system pipe network model is expanded, and the interaction between water flow in urban drainage system pipe network and overflowed water flow can be reflected more accurately. The simulation of surface water and water receding situation is suitable for urban waterlogging risk assessment and management.

3.3 Application of InfoWorks Model

Ye Chenlei [31] took Baima River area in downtown Fuzhou, a coastal city, as an example, established a hydrodynamic coupling model based on InfoWorks ICM, and verified the model parameters based on measured rainfall and liquid level data of inspection wells on a certain day. He used four kinds of return period rainfall to drive models in the respectively. On the basis of hydrodynamics model analysis, a two-dimensional hydrodynamic model was constructed based on topographic data as a supplement. The HR risk analysis method was used to carry out quantitative calculation and spatial analysis of flood risk in the area, which provided a certain technical support for typical urban flood scenario simulation and risk quantitative analysis. He Li [32] established a two-dimensional coupled drainage pipe network model of a certain area in Shanghai based on InfoWorks ICM, and calibrated and verified the model on the distribution of stagnant water points using the current measured flow data, so that the model had good representativeness and reliability. The rainwater pipe network system of the study area under different rainstorm intensity is simulated and analyzed respectively. It took into account the depth of water in the area, how long it had been standing and how overloaded the pipes were, and evaluated the drainage capacity of the current drainage pipe network system and made it clear that the load of the current drainage pipe network was the designed rainfall return period. It is found that the drainage capacity of the current drainage system is not up to 56.6% of the rainfall intensity once in 3a and assesses the overloading of pipelines and the level of waterlogging risk in his region. Zhou Tianze [33] established one-dimensional and two-dimensional coupled hydrodynamics models of a pilot area in Longhua District, Shenzhen City based on InfoWorks ICM. The calibration and validation of model parameters are carried out by comparing the measured precipitation data with the monitoring data of well water level in the pilot area. The regulation scheme can effectively improve the waterlogging situation and eliminate the waterlogging risk.

4. Conclusion

Due to the urban development and construction, the natural stagnant water, storage capacity of the ground are reduced, the drainage capacity of drainage pipe and the canal waterlogging prevention facilities is insufficient. The city’s water system is vulnerable to heavy rains. It is very important to do a good job in the prediction of flood and other disasters, the drainage work of the city, the real-time monitoring of the water conservancy system in the city, and the establishment of an effective model of urban waterlogging. Based on the current situation of water in the study area, some measures are put forward to provide some technical support for urban flood control and drainage.

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References

[1] Huang X. Study on the effect of storm flood control in small towns with complex terrain based on SWMM model. 2020/2021 Chinese Urban Planning Annual Conference and 2021 Chinese Urban Planning Academic Season, 2020: 11.

[2] Wang Lei, Bai Yang, Zhang Yigong. Research on network drainage model based on SWMM mapping and spatial geographic information, 2021, 44(09): 49-52.

[3] Zhao Ting. Discussion on regional design of LID facilities based on SWMM. Municipal Technology, 2021, 39(09): 121-123+135.

[4] Wang Li. Research on identification and optimization of waterlogging points in residential areas based on SWMM. Xi’an University of Architecture and Technology, 2021.

[5] Liu Haiwei. Construction and simulation of drainage network model based on SWMM in a district of Hefei. Anhui Jianzhu University, 2021.

[6] Gao Jiayu. Research on multi-objective layout optimization of sponge facilities in old urban area . Xi’an University of Technology, 2021.

[7] Li Jiajia. Numerical simulation of check dam failure process based on MIKE 21 model. Xi’an University of Technology, 2021.

[8] Wang Hongru. Study on simulation and early warning system of waterlogging in smart sponge city . Chongqing Jiaotong University, 2020.

[9] Qu Hongling. Journal of Water Resources and Water Transportation Engineering, 2007(04): 49-54.

[10] Qiao He. Study on utilization and regulation of stormwater resources in typical urban drainage channels. Liaoning Normal University, 2021.

[11] Tang Chongxi. Numerical simulation of hydrodynamic and water quality in Baiyangdian lake based on MIKE 21. Tianjin Polytechnic University, 2021.

[12] Wang Yu, Tang Mengjun, Dai Huichao. Correlation analysis between spawning habitat suitability of four fish and dam discharge. Water Conservancy and Hydropower Technology, 2016, 47(01): 107-112.

[13] Zhang Shuang. Simulation of flood disaster and driving influence in Xiangzhou City of Zhuhai city. Hebei University of Engineering, 2021.

[14] Wei Yingjian. Simulation study on the influence of changing environment on urban stormwater runoff and its control. Xi’an University of Technology, 2020.

[15] Li Yuanfei. Precipitation variation characteristics and current drainage network evaluation in Xiangzhou City of Zhuhai. Liaoning Normal University, 2020.

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[16] Li Shi. Research on combined water resistance effect of highway (Iron) road based on a two-dimensional coupled hydraulic model. Xi'an University of Technology, 2017.

[17] Fan Lihong. Study on the convergence mathematical model between one and two dimensions and flood risk analysis in Xisanwa basin. Tianjin University, 2016.

[18] Yan Ciyu. Study on sponge reconstruction effect of uniformed rose nanyuan residential area. Hubei University of Technology, 2020.

[19] Xue F C, Jiang J, Tian J, et al. Simulation analysis of spatial distribution of waterlogging disaster under rainstorm scenario in Hangzhou city during reoccurrence period. City and Disaster Reduction, 2021(05): 1-5.

[20] Li P, Xu Z X, Zhao G, et al. Simulation of urban rainstorm and waterlogging based on SWMM and LISflood-FP model: A case study of Jinan city. South-to-North Water Transfers and Water Science & Technology: 1-15.

[21] Xu Huijun. Study on modeling method of urban Stormwater Simulation based on SWMM Model . Water Resources Planning and Design, 2021(09): 44-49+97.

[22] Wang J J, Xu Z X, Zhao G, et al. Effect of basic-flow segmentation on urban rain flood process simulation: A case study of Jinan city. Journal of Beijing Normal University (Natural Science Edition): 1-9.

[23] Zhao Yue. Simulation of waterlogging in typical urban areas based on MIKE model and effect of drainage waterlogging removal scheme. Xi'an University of Technology, 2021.

[24] Fu C, Fu Y Z, Xiao C Y, et al. Elastic analysis of urban waterlogging based on MIKE FLOOD model. Advances In Science And Technology Of Water Resourse: 1-11.

[25] Wang X N, Peng Y, Wu J, et al. Impact analysis of urban super-standard flood disaster based on Mike coupling model. Hydropower energy Science, 2021, 39(08): 94-98.

[26] Wang Huaizhi. Application of MIKE model in urban overstandard flood risk analysis. Engineering and Construction, 2021, 35(04): 723-724+726.

[27] Zhang Y X, Hao M, Fang Q, et al. Simulation of Flood control and drainage in newly built urban areas based on Mike Flood coupling model. China Rural Water and Hydropower, 1-16.

[28] Charlie. Application of MIKE FLOOD coupling model in urban super standard flood prevention plan. Water Conservancy Technology Supervision, 2021(07): 57-60.

[29] Zhang xu. Simulation of waterlogging in Fengxi New Town in Xi Xian New Area based on MIKE FLOOD coupling model. Xi'an University of Technology, 2021.

[30] Luan Z Y, Jin Q, Zhao S Y, et al. Urban waterlogging simulation based on MIKE FLOOD coupling model. Water resources protection, 2021, 37(02): 81-88.

[31] Ye C L, Xu Z X, Lei X H, et al. Urban flood simulation and risk analysis based on InfoWorks ICM: A case study of Baima River area in Fuzhou city. Journal of Beijing Normal University (Natural Science Edition): 1-11.

[32] He Li. Analysis of drainage capacity of drainage system in a district of Shanghai based on InfoWorks ICM-2D coupling model. China Municipal Engineering, 2021(04): 36-40+107.

[33] Zhou Tianze, Liang Qian, Wang Yiying. Flood control and drought relief in China based on InfoWorks ICM model. China Flood & Drought Management, 2021, 31(05): 12-19.