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The application of storm water management model in comprehensive planning of urban drainage and flood control

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ABSTRACT

The drainage pipeline network model uses modern hydrology, hydraulics, mathematical modeling and computerized simulation to simulate the characteristics of urban drainage pipeline network system. Storm Water Management Model (SWMM for short) is the most widely used tool for modeling and analysis of drainage pipeline network model. It introduces SWMM modeling, simulation evaluation and analysis process, and carries out evaluation on drainage capacity of drainage pipeline network, and analysis on waterlogging causes and risks. The results show that, the SWMM has very good simulation results, it can provide a basis for scientific decision-making in urban drainage pipeline network planning.

KEYWORDS

SWMM; Simulation; Waterlogging; Drainage pipeline network.

INTRODUCTION

The drainage pipeline network is an important part of basic construction of urban facilities and industrial enterprises, it is a very important urban infrastructure, it plays an important role in flood control and drainage, meanwhile, it is also an important engineering measure for controlling water pollution, and improving and protecting the environment. At present, the urban drainage pipeline network system of China is experiencing a severe test due to the reasons such as urban development, natural climate changes, design defects, construction irregularities, ineffective maintenance, etc..

China traditional urban drainage pipeline network planning and design is based on hydrological and hydraulic theories and engineering experience, it uses constant hydraulic theory to calculate the catchment process of network, and uses empirical equation to calculate hydraulics of pipeline, the designed drainage pipeline network can not reflect the real state of the water flow inside the network, as well as the water flow change process inside the network along with the time. Therefore, it inevitably produces many errors, so the drainage pipeline network system of most Chinese cities has defects of different degrees. In 2013, the *Notice on Promoting Construction Work of Urban Drainage and Flood Control Network System (G.B.F.[2013]No.23)* enacted by the General Office of the State Council of the People's Republic of China requested that *"the urban drainage facilities planning shall be formulated before the end of 2014 on basis of the status quo"*. The *Formulation Outline for Comprehensive Planning of Urban Drainage (Rainfall) and Flood Control* ([2013]No.98) enacted by The Ministry of Housing and Urban-Rural Development of the People’s Republic of China[2] suggested that hydraulic model shall be used for assistance in urban waterlogging planning.

Drainage pipeline network model is actually the prototypal abstraction and generalization of the drainage pipeline network system. Drainage pipeline network model uses knowledge of modern hydrology and hydraulics, mathematical modeling and computer simulation to stimulate the characteristics of urban drainage pipeline network system, thus to make scientific decisions for related problems. Starting from the 1960s of the 20th century, many researchers have carried out extensive study and development on urban drainage system stimulation, there have been a large number of statistical models, mechanistic models and management planning models. In 1971, the Environmental Protection Agency (EPA) of the United States funded and developed Storm Water Management Model (SWMM for short), it really marked the beginning of computerized modeling for urban drainage pipeline network[1-2]. Subsequently, Illinois Urban Drainage Area Simulator (ILLUDAS for short), Storage Treatment Overflow Runoff Model (STORM for short) developed by the Hydrologic Engineering Center of the United States Army Corps of Engineers (USACE), etc. successively came out. To construct a drainage pipeline network model is an important foundation for analyzing rainfall runoff rules of drainage basin, catchment rules of drainage pipeline network and operational characteristics of drainage pipeline network system.

MODEL AND METHODOLOGY

Basic equation for model simulation--Saint Venant equations

Catchment process of drainage pipeline network system is a unsteady flow process with very complex flow conditions, unsteady flow simulation method is needed for simulation calculation. The basic equation for describing unsteady flow of drainage pipeline network is the famous Saint-Venant equations. The Saint-Venant equations belong to first order quasilinear hyperbolic partial differential equations[3], it was developed by the French scientist Adhémar Jean Claude Barré de Saint-Venant in 1871. Its typical form is equation (1) as below:

$$\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial Q}{\partial x} = q \\ \dfrac{\partial Q}{\partial t} + \dfrac{2Q}{A}\dfrac{\partial Q}{\partial x} + gA\dfrac{\partial h}{\partial x} + gA(S_f - S_0) = 0 \end{cases}$$

Where: H=sectional water depth perpendicular to the flow direction, Q=flowrate, V=flow velocity, A=watered sectional area perpendicular to the flow direction, B=water surface width, q=side flowrate of unit pipeline, x=horizontal distance along with the water flow, t=time, G=acceleration of gravity, $S_{f=}$friction slope, $S_{0=}$ bottom slope of pipeline.

SWMM model

The SWMM developed by Environmental Protection Agency (EPA for short) is a dynamic rainfall-runoff simulation model[4], this model can be used for carrying out dynamic simulation for a single storm or storm runoff caused by continuous rainfall, thus to solve water quantity and quality problems associated with urban drainage system. It was one of the earliest and the most widely used urban drainage management models. It has been updated for many times since its first development in 1971. The latest version is 5.1.

SWMM divides the hydrologic and hydraulic factors of urban drainage pipeline network into three types, namely, line, node and catchment. Non-linear reservoir model is used to stimulate surface runoff, and Saint-Venant equations are used to calculate the conveying process of the pipeline network.

SWMM model can be used for planning and design, scenario analysis and programme evaluation of rainfall runoff in urban areas, combined pipeline, drainage pipeline and other drainage system.

Establishment of SWMM model

The establishment of SWMM model mainly has two stages[5-6]: (1) data collection; (2) model parameters identification.

Data collection

(1) Storm rainfall data

Rainfall data is an important stimulation boundary conditions of SWMM model, of which, storm intensity is the most basic data. If you want to get accurate and reasonable stimulation results, you need to collect storm data in recently 30 years, especially the storm intensity which has resulted in significant ponding events.

Rainfall data of every consecutive 5 minutes of many years is the best boundary conditions of SWMM model. While using design storm to carry out rainfall stimulation analysis, the rainfall peak coefficient r must be explicitly determined, if it is very difficult to obtain the actual data of rainfall peak coefficient r, r shall be 0.3~0.5 according to the experience at home and abroad. Rainfall data of many consecutive years in adjacent similar cities can also be used as aided analysis for SWMM model.

(2)Underground pipe network data

Spatial distribution and elevation data of drainage pipeline network is the most important structural data of SWMM model, the level of detail of the data determines the contents and accuracy of model analysis. In addition, in the regions adopting rainfall and sewage combination, relevant date of drainage pipe network shall also be used to build combined pipeline network model.

(3) Collection of underlying surface data

Underlying surface data is important basic data for carrying out catchment division and parameters calculation. It is needed to correctly find out the land utilization type within the modeling regional scope (roofing, road surface, green land surface, surface of public service facilities, water surface and so on. Terrain data can be obtained from surveying and mapping department in most cities, if it is very difficult to obtain accurate terrain data, land development and utilization type data can be used for identification of surface permeability.

(4) Surface elevation data collection

Surface elevation data is important data for identification of surface slope. Normally, you can obtain elevation or contour data and use ArcGIS to produce digital elevation model (DEM for short) and calculate the slope.

(5) Monitoring data collection

Drainage monitoring data is the data used for model validation. The drainage pipeline flowrate monitoring data from the management department is the most reliable model validation data. However, due to costly drainage pipeline monitoring equipments, currently, only a handful of developed cities have drainage pipeline flowrate monitoring data; in the regions without any monitoring conditions, pump station watering flowrate data can be used for model validation. Additionally, the on-site investigation data like ponding position and severity is accessible, it can be used qualitatively for model validation.

Model parameter identification

SWMM is a complex distributed network model. SWMM parameters identification has the following steps[4]: (1) determine modeling purpose; (2) initial parameters of estimated model; (3) collection of data needed for calibration; (4)use initial parameters for simulation, and analyze the results; (5) manual parameters adjustment (repeated debugging) or rough calibration; (6) analysis on parameter sensitivity degree; (7) fine calibration of model parameters.

Evaluation and analysis of model simulation

SWMM can use the status quo of drainage system to carry out network drainage capacity evaluation, analysis on waterlogging causes and waterlogging risk evaluation.

Drainage capability evaluation

The key point of using SWMM to carry out network drainage capacity evaluation is the determination of evaluation criteria. Some researchers uses the filling degree of pipeline network as evaluation criteria, they think only the non-fully-filled pipeline can meet relevant requirements; actually, the rainfall pipeline networks are all designed on basis of fully-filled pipeline, therefore, the filling degree shall be used as the evaluation criteria ca n underestimate the drainage capacity of pipeline network. The author of this paper considers *"the bottom of residential and commercial buildings shall not be watered; the ponding depth of one lane of roads shall not exceed 15cm"* as evaluation criteria.

Analysis on waterlogging causes

The causes for waterlogging problems are complicated, they are often caused by several reasons. SWMM model mainly reflects the waterlogging caused by structural problems of drainage and flood control system (including low-lying, downstream underpinning, low design criteria and so on), longitudinal section drawings of water points and fullness map distribution can be used for identification.

Waterlogging risk evaluation

Use SWMM to carry out urban waterlogging risk evaluation: use computerized stimulation to obtain stormwater runoff flow state, water level changes, ponding scope, flooding time, etc., use single indicator or multiple indicators to comprehensively evaluate the risks of urban waterlogging disasters; classify the waterlogging risk levels of the cities according to the importance and sensitivity of urban areas.

RESULTS

Use SWMM to build drainage system model of studied area, and use sewage treatment plant input flowrate, pump station flowrate and ponding roads distribution of three rainfalls to validate the model, except for few stimulation errors in some pump stations, the left validation results all meet the requirements of the model. Use the validated model to carry out systematic analysis for network drainage capacity, waterlogging characteristics and causes. The results are as shown in Figure 1.

As shown in evaluation results Figure 1: the downstream of the pipeline has sufficient drainage capacity, however, there is stagnant water in the upstream, it means that the upstream pipeline network bears too large load; and the stagnant water mainly appears in the low-lying areas of upper reaches. Use SWMM to analyze the causes for ponding in this region and find that the main reasons for ponding are low-lying terrain and low pipeline network design capacity.

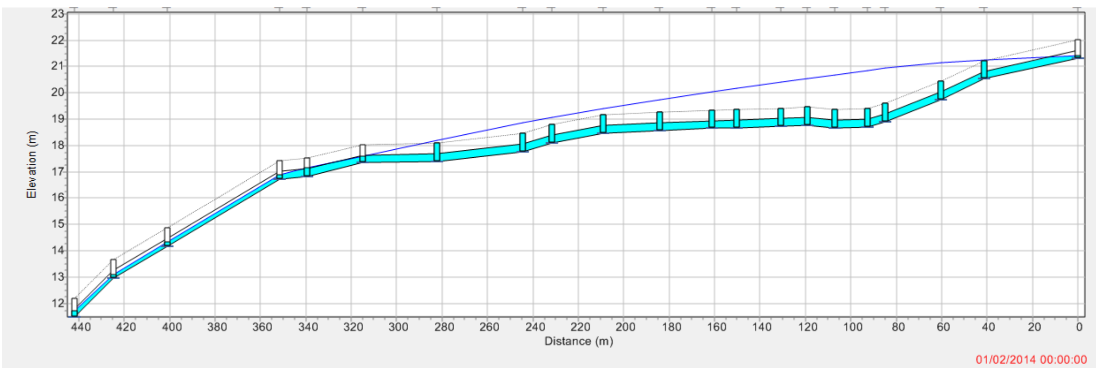

Figure 1 : Example of pipeline network drainage evaluation and ponding causes analysis results

During the urban development process, the elevation of underground pipeline is changed due to land subsidence in some regions, and affects the load of the pipeline, such problems can only be figured out by virtue of SWMM by collecting latest accurate data of pipeline network and topographic mapping.

Use SWMM to simulate the ponding situations of the manhole (as shown in Figure 2). Stimulation results as shown in Figure 2: the ponding situations of most manholes are in blue (i.e., safe state), only few manholes are in red, it means that there are some ponding and waterlogging risks

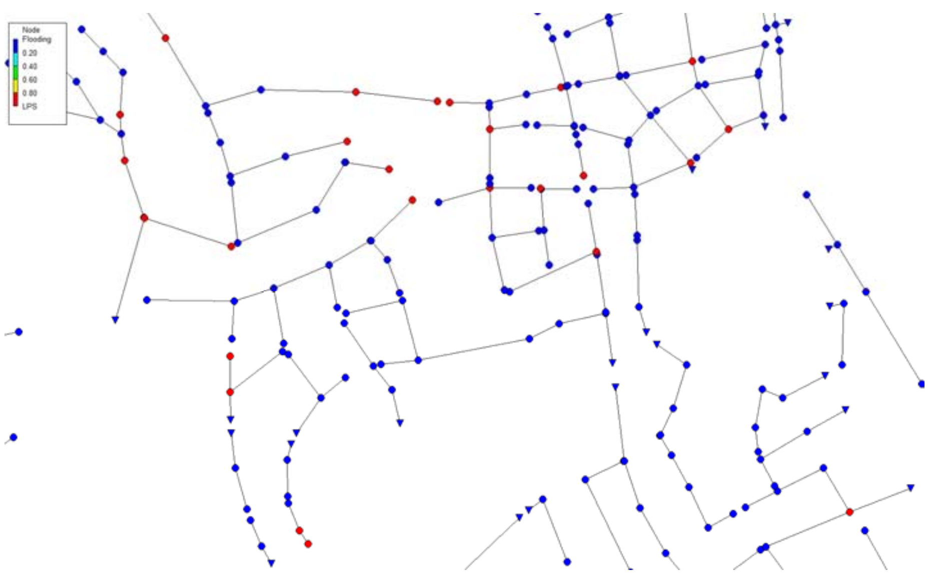

Figure 2 : Example of SWMM manhole ponding simulation results

CONCLUSION

SWMM modeling is flexible and convenient, corresponding models can be built for data of different precisions, however, rainfall, pipeline network, surface and monitoring data are essential data, the richer the obtained basic data is, the more accurate the stimulation results will be, and the more accurate the obtained evaluation and analysis will be. SWMM can be easily applied to the formulation of comprehensive planning of urban drainage and flood control (including network drainage capacity evaluation, analysis on waterlogging causes and waterlogging risk evaluation). According to the actual stimulation analysis, SWMM has good stimulation effects, it can fully reflect actual situations, it can provide a basis for scientific decision-making in urban drainage pipeline network planning.

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