Storm Rainfall-Runoff Quality Analysis of Typical Catchment Using SWMM

Xiao-juan CHEN¹, Bo-yang SUN², Xiao-hua YANG³ and Hong-qing Li⁴

¹,⁴Changjiang Water Resources Protection Institute, No. 515, QinTai Avenue, HanYang District, Wuhan 430051, P.R. China
²,³State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, No. 19, XinJie KouWai St., HaiDian District, Beijing 100875, P. R. China

*Corresponding author

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Abstract. The RUNOFF block of EPA’s storm water management model (SWMM) was used to simulate the quality of urban storm water runoff from relatively small site in Beijing. We monitored and sampled runoff during several storm rainfall events and analyzed the concentration of total phosphorus (TP), nitrate nitrogen(NO₃-N), ammonia nitrogen(NH₄-N), lead (Pb), copper(Cu), zinc(Zn) and cadmium(Cd) totally seven indicators, which were used for calibration of the model. Application of the model was done using the Green-Ampt equation for infiltration loss computation, a pollutant accumulation equation using a saturated build-up equation, and a power wash-off equation dependent on the predicted runoff rate. Complete rainfall events were used for verification of the model, which showed a good comparison with observed data for pollutant loadings. The results of this study suggest that SWMM can express in detail the storm water pollution patterns from diverse rainfall scenarios in Beijing, and pollution loading has a positive correlation with rainfall intensity.

Introduction

Urban non-point source pollution control and flood management are the important frontiers of scientific research. Urban activities may increase the contribution of pollutants to amounts that threaten the quality of receiving water bodies[1]. To achieve effective rainstorm management, appropriate model must be selected to accurately predict and simulate the process of storm runoff and impounded surface water. SWMM (Storm Water Management Model) is a dynamic rainfall-runoff simulation model, developed by the EPA for the design and management of urban rainstorm, which can be used for a session or long-term simulation of water quality and quantity in urban areas [2]. As a distributed, continuous simulation model, and one model that can clearly simulate the hydrologic hydraulics elements involved in the phenomenon of urban drainage, SWMM has been widely used in urban non-point source pollution control.

Previous studies concentrated on validating SWMM in large catchments, mainly using continuous simulation, durations varying from months to several years [3,4]. This paper presents the calibration and verification of SWMM during relatively short duration, frequent, single events in small urban catchments. The purpose was to identify urban storm rainfall runoff pollution from different rainfall intensity for application in control design of Beijing water quality [5].

Materials and Methods

Study Area Description

A typical urban region in Beijing is selected in this research. The underlying surface consisted of roads, roofs and grassland. The land area is 29.5 hectares, of which the impermeable area accounts for 54.7% of the total area. Main drainage pipe network in the area are along the roads, mostly in the north and south direction. The rainfall-runoff from the east-west line of main pipe drainage runs into the nearest node respectively, and discharges into the municipal drainage pipe network by the
According to the feature of the terrain and rain pipe network layout in the study area, the whole area were divided into thirteen drainage areas, 112 nodes, 116 pipelines, and one outlet.

**SWMM**

The EPA's SWMM is a comprehensive hydrological and water quality simulation model developed primarily for urban areas. Hydrological computations in the RUNOFF block are based on the theory of non-linear reservoirs. The Horton equation was used here. Here are the functions for computing accumulation and wash-off of pollutants in SWMM [6,7].

The saturation function:

\[
P = Pt + Pmxt / (k + t)\]

Where \( P \) is the constituent quantity at time, kg/ha; \( Pt \) for the catchment area pollutant cumulants last time through td sunny day, kg; \( Pm \) for the catchment area maximum cumulative amount of pollutants, kg; \( t \) for days from recent rain event; \( K \) for the half saturation cumulative constant, d.

Exponential washing: wash load (W) unit is per hour for quality, is proportional to the product of \( C_2 \) power of runoff and growth remaining amount.

\[
W = C_1 q C_2 B\]

Where \( W \) is the constituent load washed off at time, kg/s; \( C_1 \) is the scouring coefficient; \( C_2 \) is the Flushing index; \( Q \) is the flow rate of per unit area, mm/h; \( B \) is surface contaminants cumulate of per unit area, Kg/ha.

**Sample Point Layout and Data Collecting**

**Sampling Point Layout.** For a comprehensive understanding of non-point source pollution status in the study area, expand the scope and implement actual rainfall monitoring, we selected five typical sampling points, respectively: pavement sampling points, green land sampling points, parking lot sampling point, roof catchments sampling point, export sampling points, and collect the actual rainwater as samples.

**Data Collecting.** For each sampling point of rainwater well or outfall, use some homemade tools to collect water samples with polyethylene bottle, and for the first 30 min since runoff started, pick samples every 5 min; 30 to 60 min, every 15 min pick one sample; after 60 min until the end of runoff, every 30 min pick 1 sample. After collecting samples, labelling, number them, and record the sampling site, date, starting and ending times for sampling, etc.

**Swmm Calibration and Validation**

Calibration and validation of the SWMM system required that the dominant parameters of each conceptual component be determined so that the outputs can present the real response of the catchment [8]. The calibration process needed to include adjustments of the model control parameters to optimize the prediction results, which were based on the previous researches and the actual condition of this catchment, hydrology and pollution parameters about were selected and validated with the monitored data [9,10]. Put the rainfall data that rain gauge measured into SWMM model, calibration each module parameter. The monitored data and simulated data of TP, TN, Cu, Zn were compared. Using MATLAB to test the fitting degree of three kinds of water pollutants, analysis shows that the fitting degree of TP, Cu, Zn and TN were 0.9453, 0.9094, 0.8629 and 0.9264, the fitting error is 0.024, 0.0018, 0.0146 and 0.0093 respectively. By this token, SWMM model simulation accuracy is relatively higher, simulation and measured results are very close.

**Results and Analysis**

**Data Analysis Result**

Each sampling point monitor six effective rainfall (8-50mm), collect and analysis of 329 effective water samples. Monitoring results of rainfall and runoff show that the non-point source pollution of
study area is serious. The average density of NH$_4$-N, TN from road surface runoff are 5.16 mg/L, 20.53 mg/L, respectively more than 2.5 times, 10 times beyond the national standards for surface water environmental V class; The average density of NH$_4$-N, TN from school parking lot are 4.83 mg/L, 14.98 mg/L, respectively more than 2 times, 7 times beyond the national standards for surface water environmental V class.

The average density of NH$_4$-N, TN, TP from surface runoff at the outlet of catchment area were 4.86 mg/L, 20.56 mg/L, 0.59 mg/L, respectively more than 2 times, ten times, and 1 times beyond national standards for surface water environmental V class. Also it can be seen, the pollution of catchment area outlet and pavement are relatively serious, then parking lots and roof, the green land pollution is lightest. Combined with actual situation, the outlet of catchment area is located near the east gate, and the main road has more vehicle and pedestrian, as a result, the pollution is heavier.

**Pollutant Load under Different Rainfall Intensity**

**Rainfall event description.** Rainfall information in July and August were measured in study area, totally six rainfall events. The rainfall interval is two minutes, and rain type chose cumulative curve in model simulation. The rainfall data representing different intensity, and according to the rain type definition, there are totally 2 small rain, 3 moderate rain, one rainstorm.

**Simulation on Export Pollutant Concentration.** According to the monitoring results of water quality of rainfall runoff in catchment area, this article selects Cu, TP, TN and Zn as four main pollution factors in the study area for the characterization of rainfall runoff non-point source pollution.

![Figure 1. Export concentration change of different pollutants.](image)

As can be seen from the figures above, pollutants concentration sorting from high to low under different rainfall events are 809, 730, 813, 729, 831, all of the four pollutants follows. Combined with features of different rainfall events and the regional characteristics, we can get conclusion that despite the big rainfall intensity of 831, there was a heavy rain the day before, which means the number of pre-drought day is zero; and although rainfall intensity of 809 is small, the number of pre-drought day was five. All in all, Export pollutant concentration is by joint decision of rainfall intensity and drought conditions.

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Conclusions

This paper describes the application of calibrated water dynamic model—SWMM, which was used to simulate non-point source pollution of urban rainfall runoff under different rainfall intensity scenario.

1. The constructed urban rainfall runoff dynamic model which based on SWMM can simulate the whole dynamic process of urban rainfall runoff, and can dynamically display all the simulation output, query at any time, any node, and any pipe system parameters and the simulation results.

2. According to different rainfall scenario simulation result, as the rainfall intensity increasing, the total runoff increased significantly, while the increase amplitude decreases; the total export pollution load has positive correlation with rainfall intensity, the greater the rainfall intensity, the greater the total pollutants discharge load, while the increase trend is leveling off.

3. Pollutant concentration of the export and sub-basins under different rainfall intensity were simulated, and the results show that export pollutant concentration is by joint decision of rainfall intensity and drought conditions, and under the same rainfall condition, and the greater the impervious area ratio, the greater the concentration of pollutants.

4. SWMM model were used for scenario simulation of the dynamic change of water quality under non-point source pollution, and it also needs further inspection on the effect of constructed model in urban non-point source pollution simulation and prediction.

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