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Stormwater Quantity and Quality Modeling in the Urban Business District of Suzhou City Using SWMM Model

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ABSTRACT

Urbanization has altered the sources, processes, and sinks of nonpoint source (NPS) pollution in cities, substantially increasing the pollution load carried by urban runoff into receiving waters. Urban runoff pollution is therefore a focal point of current NPS research. This paper analyzes stormwater quantity and quality in the urban business district of Suzhou using the Storm Water Management Model (SWMM), a software platform valued for its graphical capabilities and rapid convergence toward optimal design parameters. The model was driven by rainfall data from three events — May 5, June 20, and June 26, 2024 — and hydraulic calibration, together with runoff pollution calculations (TSS, COD), was performed through an iterative process of parameter and error adjustment.

The results demonstrate the strong predictive capability of the SWMM model once properly calibrated against measured data. Hydraulic validation showed a close match in both the timing and magnitude of flow variations, with simulated total runoff volumes differing from measured volumes by only 2.12% and 7.9%. For water-quality validation, performed using the rainfall event of June 26, 2024, the agreement between simulated and measured pollutant loads reached 98% for TSS and 90% for COD, confirming the model's strong predictive capacity. Modeling the quantity and quality of urban runoff pollution enables urban planning professionals to monitor environmental conditions in support of urban sustainability.

Keywords: *runoff pollution; stormwater management; SWMM model; Suzhou*

INTRODUCTION

Urbanization and climate change are intensifying stormwater management challenges in cities worldwide, increasing both the frequency and severity of pluvial flooding, drainage-system overloads, and the associated socio-economic losses. Effective stormwater management now requires robust, physics-based modeling tools capable of simulating complex rainfall–runoff processes, flow routing within sewer networks, and the performance of structural and nature-based mitigation measures across a wide range of storm scenarios (Maki-Asiala et al., 2026; Girma et al., 2025; Zafarmomen et al., 2026).

Human populations are becoming increasingly urbanized, with approximately half of the world's population now residing

in urban areas (Cohen, 2003). This shift has altered not only the hydrologic flow regime but also the chemical and biological composition of stormwater runoff from developing areas. As land is developed, a catchment's natural ability to buffer hydrologic variability is progressively lost infiltration capacity declines as impervious surfaces expand and native soils and vegetation are disturbed (Gbafa et al., 2017), while the natural retention and detention capacity of the catchment is reduced through the channelization of waterways and the installation of formal drainage infrastructure such as pipes and gutters. Human activity also introduces chemical and biological constituents into the catchment: trace metals, suspended solids, nutrients, pesticides, petroleum products, and E. coli and fecal coliform bacteria are typically found at higher concentrations in urbanized and urbanizing areas than in natural systems, reflecting the greater density of people, vehicles, roads, and building materials across the landscape. Municipal, state, and federal agencies have substantially improved stormwater management in developed and developing areas within their jurisdictions, yet urbanization remains the dominant form of land-use change affecting water quality, hydrology, the physical properties of watersheds, and their potential for nonpoint source (NPS) pollution.

The U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) has emerged as one of the most widely adopted tools for urban stormwater planning, design, and analysis. Over the past two decades, SWMM has been applied globally to assess drainage capacity, evaluate low-impact development (LID) and green infrastructure strategies, quantify the impact of climate change on urban flood risk, and support real-time control and decision-making frameworks. Its semi-distributed hydrologic formulation, flexible hydraulic solvers, explicit representation of LID controls, and open architecture have made it a preferred platform for both research and practice (Girma et al., 2025; Rosario et al., 2026). Despite its extensive use, however, the SWMM literature remains fragmented across application domains, geographic contexts, and methodological approaches. Studies vary widely in model setup, calibration practice, performance metrics, and coupling with complementary tools such as GIS, two-dimensional hydraulic models, and machine-learning surrogates. This heterogeneity complicates the synthesis of best practices, the transfer of lessons learned between regions, and the design of standardized protocols for SWMM-based stormwater modeling, particularly in data-scarce and rapidly urbanizing environments (Girma et al., 2025).

MATERIALS & METHODS

Study Area

Suzhou is located at the center of the Yangtze River Delta (Figure 1), bordered by Jiangsu and Zhejiang Provinces to the south, Shanghai to the east, Wuxi City to the west, and the Yangtze River to the north. Water bodies cover 42% of the city, which is intersected from north to south by the Beijing–Hangzhou Grand Canal. Suzhou is located at 31°18′00″N, 120°36′00″E, covers an area of 8,488 km², and has a population of 8.6 million. Mean annual temperature and precipitation are 15.5°C and 1,100 mm, respectively.



Figure 1: Study area

Suzhou lies in a subtropical monsoon zone, giving it a mild, humid climate with four distinct seasons. Winters are cold and dry, dominated by continental air masses moving in from the northwest, while summers are warm and humid under the influence of maritime air, with alternating wet and dry spells.

SWMM model

The U.S. EPA's Storm Water Management Model (SWMM) is one of the most widely used dynamic hydrologic–hydraulic tools for urban stormwater planning, design, and analysis worldwide. Over the past two decades, SWMM-based studies have expanded from conventional drainage design toward integrated urban flood-risk assessment, low-impact development (LID) evaluation, climate-change adaptation, and, more recently, hybrid physics–machine-learning frameworks (Zafarmomen et al., 2026).

Hydraulic calibration

SWMM parameters fall into two groups (Delleur, 1982; Liong et al., 1991). Traditional parameters include roughness coefficients, surface depression storage, and infiltration, while non-traditional calibration parameters concern the width, slope, and impervious fraction of the subcatchments. Calibration was carried out through an iterative trial-and-error process, adjusting the parameters listed in Table 1. The rainfall events of June 20 and June 26, 2024, were used for this calibration.

Table 1: Hydraulic calibration parameters

Parameter	Allowed range of variation	Initial value
Average impervious area	± 10%	48.61%
Average width	± 30%	10.8
Average slope	± 30%	0.3%
Surface storage — impervious area	0.3 – 2.5 mm*	1.3
Surface storage — pervious area	2.5 – 5.1 mm**	3.8
Green–Ampt infiltration — suction	9.7 – 253	9.7
Green–Ampt infiltration — conductivity	8.6 – 119	8.6
Green–Ampt infiltration — initial deficit (fraction)	0.37 – 0.50	0.435
Manning's n — pervious area	0.02 – 0.45*	0.15
Manning's n — impervious area	0.010 – 0.015*	0.012
Manning's n — pipes	0.011 – 0.013**	0.011

** Huber and Dickinson (1988). ** Tsihrintzis and Hamid (1998).*

Calibration consisted of fitting the simulated hydrograph to the measured flow data using two objective functions: the relative error in runoff volume (dV) and the relative error in

peak runoff (dP), evaluated for the rainfall events of June 20, 2024, and June 26, 2024 (Table 2):

$$dV = [(Vm - Vs) / Vm] \times 100 \quad (E1)$$

$$dP = [(Pm - Ps) / Pm] \times 100 \quad (E2)$$

where the subscripts m and s denote the measured and simulated flow, respectively.

Table 2: Relative error in runoff volume (dV) and peak flow (dP)

Date	Vm (m³)	Vs (m³)	dV (%)	Pm (m³/s)	Ps (m³/s)	dP (%)
2024-06-26	443.558	434.131	2.12	0.181	0.207	-14.68
2024-06-20	106.292	97.827	7.9	0.075	0.093	-24.58

Quality calibration

The rainfall event of May 5, 2024, was selected for water-quality calibration. Pollutant buildup was represented by the saturation function (E3), which increases at an initially linear rate and progressively declines over time as it approaches saturation:

$$C(t) = C1 \cdot t / (C2 + t) \quad (E3)$$

where C1 is the maximum possible buildup (mass per unit area or per unit curb length) and C2 is the half-saturation constant (the number of days required to reach half of the maximum buildup).

Wash off describes the transport of pollutants across the catchment surface during a runoff event. The wash off load, W, expressed in mass per hour (E4), is proportional to the product of the runoff rate raised to a given power and the remaining pollutant buildup:

$$W = C1 \cdot q^{C2} \cdot B \quad (E4)$$

where C1 is the wash off coefficient, C2 is the wash off exponent, q is the runoff rate per unit area (in./h or mm/h), and B is the pollutant buildup. Buildup here denotes total mass rather than mass per unit area or curb length, and both the buildup and wash off mass units match those used to express pollutant concentration (mg, µg, or counts).

RESULT AND DISCUSSION

Hydraulic calibration

The runoff coefficients strongly influenced both the total runoff volume and the peak flows, while slope, width, and Manning's roughness coefficient primarily affected the timing of the peak flows. These results fall within a reasonable margin of error for parameter estimation (Bennani Baiti, 2017; Field et al., 1996); using an automatic SWMM calibration module, these studies obtained reductions relative to the initial values ranging between 5% and 25% for impervious areas and around 8% for subcatchment width. Surface storage, infiltration, and roughness parameters were adjusted within their established ranges (Peterson and Wicks, 2006).

Table 3: Hydraulic calibration parameters of the model

Parameter	Calibrated value
Average impervious area	48.62%
Average width	10.82 m
Average slope	0.15%
Surface storage — impervious area	1.3 mm
Surface storage — pervious area	0.05 mm
Green–Ampt infiltration — suction head	9.7
Green–Ampt infiltration — conductivity	8.6
Green–Ampt infiltration — initial deficit	0.435
Manning's n — pervious area	0.15
Manning's n — impervious area	0.012
Manning's n — pipes	0.011

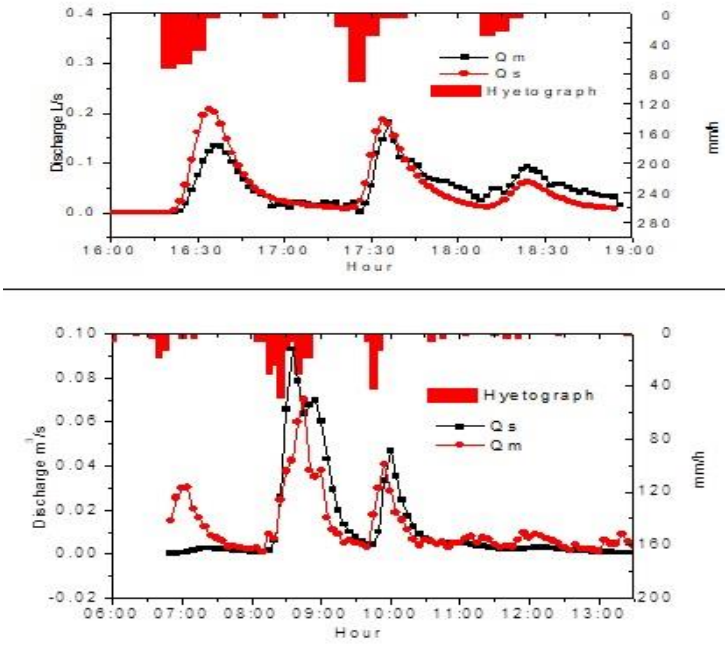


Figure 2: Observed vs. simulated discharge for June 20 and June 26, 2024, calibration events

For the rainfall event of June 26, 2024 (Figure 2), the calibrated model closely reproduced all variations in the measured flow. Simulated peak flows were, on average, 14.68% higher than those measured, and the timing of the simulated peaks matched the observations closely (Field et al., 1996). Potential measurement errors in the observed flows should also be considered: Maksimovic and Radojkovic (1986) estimated an uncertainty of 5–25% in such measurements. Total simulated and measured volumes differed by only 2.12%. Overall, the hydraulic predictions were accurate, particularly given the long duration and variable intensity of the rainfall event.

Quality calibration

Figure 3 presents the quality calibration results for TSS and COD using the rainfall event of May 5, 2024. The simulated and measured peak pollutant concentrations agreed closely, with the predicted timing of the peaks differing from the observed timing by less than five minutes. Good agreement was also obtained at the low points of the pollutographs, as well as at their initial and final values. The total pollutant loads measured and simulated at the end of the rainfall event agreed to be within 95% of TSS and 91% for COD. These results confirm that an accurate fit to the variation of each pollutant during a rainfall event can be achieved through appropriate adjustment of the model's input parameters (Piveteau, 2021).

Based on the hyetograph for the June 26, 2024, rainfall event, the storm lasted 135 minutes (16:15–18:30) and comprised three episodes of 15–20 minutes each, with peak intensities of 80 mm/h occurring during the first two episodes. The two observed runoff peaks correspond to the end of each period of peak rainfall intensity. Simulated runoff errors were very small for the last two episodes (≤ 0.025 L/s) but notably larger for the first episode (0.075 L/s).

The rainfall event of June 20, 2024, extended from 06:30 to 12:00, with its principal peak occurring between 08:00 and 09:00. Errors associated with this peak and with the initial peak were relatively large (0.03 m^3/s, or 30 L/s), whereas errors for the subsequent peaks were minimal. The discrepancies observed in simulated runoff at the onset of this event are likely attributable to how initial soil imperviousness is represented in the model.

For the TSS and COD concentrations recorded during the May 5, 2024, rainfall event — which lasted 300 minutes (12:15–17:15) according to the hyetograph — errors were minimal (25 mg/L for both TSS and COD). Peak TSS and COD concentrations occurred during the first, most intense rainfall peak, with a lag of 120 minutes. Qualitative simulations of runoff pollution for June 26, 2024, event yielded near-zero errors for both TSS and COD, confirming the model's robustness for qualitative runoff analysis.

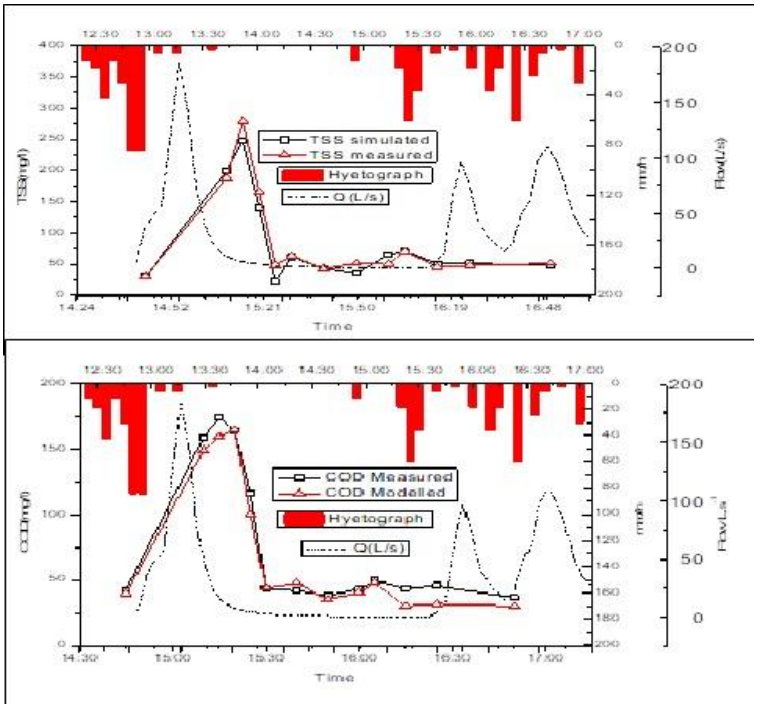


Figure 3: Calibration of TSS and COD using the rainfall event of May 5, 2024

Quality validation of the model was performed using the rainfall event of June 26, 2024 (Figure 4), yielding agreement between simulated and measured pollutant loads of 98% for TSS and 90% for COD — confirming the model's strong predictive capacity.

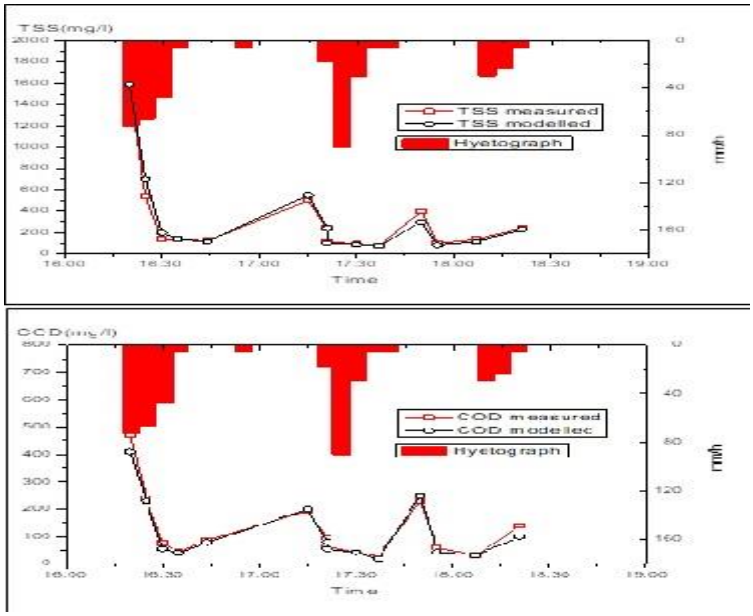


Figure 4: Calibration of TSS and COD using the rainfall event of June 26, 2024

CONCLUSION

Calibrated stormwater models tailored to specific regions are essential for predicting the future effects of pollutants on receiving water bodies. Such models should be used to evaluate existing best management practices (BMPs) and to improve or update these systems for more effective performance.

The methodology adopted in this study — generating coefficients for future application to a specific geographic location — provides an effective means of extrapolating input parameter values across a range of conditions and land uses. Similar studies should be undertaken to derive parameters for other common urban pollutants. Overall, SWMM performed well in predicting both quantity and quality parameters; however, given the effort required to learn and apply the model, its use may be most effective for large catchments encompassing diverse land uses and complex storm-drain networks.

Using rainfall–runoff observation data and empirically derived coefficients for the study area, a SWMM-based model was developed and applied to assess runoff pollution in the Xiangjiang Road catchment of Suzhou. Quality calibration was carried out following hydraulic calibration of the model. The model represented infiltration losses using the Green–Ampt equation, pollutant accumulation using a saturation buildup function dependent on the number of antecedent dry days, and pollutant washoff using an exponential function dependent on the predicted runoff rate.

Hydraulic calibration produced relatively large errors during the first two rainfall events, likely related to initial soil permeability; these errors decreased in subsequent events. Flood-retention basins and flow-retarding structures were likely not represented in the SWMM hydraulic model. Results from the qualitative pollution calibration confirm a significant time lag together with high initial TSS and COD concentrations, which decrease over time through dilution.

Declaration by Authors

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Conflict of Interest: No conflicts of interest declared.

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