Progress in Research and Development of Storm Water Management Model: Applications from China and Abroad

Abstract

The Storm Water Management Model (SWMM), developed by the U.S. Environmental Protection Agency (EPA) in the 1970s, is a widely used hydrological and hydraulic modeling tool for simulating urban stormwater quantity and quality. It enables the comprehensive simulation of rainfall-runoff processes, including precipitation events, surface runoff generation, infiltration, and pollutant transport, as well as flow routing through drainage networks, storage units, and treatment facilities. SWMM has been extensively applied in urban flood risk assessment, rainwater harvesting system design, low-impact development (LID) evaluation, and the analysis of complex hydrogeological conditions, such as karst terrains. This paper presents a systematic review of the historical development, technical improvements, and derivative models of SWMM. It further examines current limitations in model performance and application scope, and proposes future research directions aimed at enhancing its accuracy, adaptability, and integration with real-time monitoring and climate change scenarios.

**Keywords**: surface runoff, stormwater retention, low-impact development, total maximum daily load, rainfall frequency method

**Introduction**

1. Development and application of SWMM

The Storm Water Management Model (SWMM), developed by the U.S. Environmental Protection Agency (EPA), is a comprehensive hydrological model for urban stormwater runoff simulation and drainage system analysis. Since its release in 1971, it has been continuously updated and refined, evolving to version SWMM 5.2. Widely applied in urban flood modeling, sponge city development, water pollution control, and drainage system design, SWMM demonstrates dynamic simulation capabilities covering the entire process from urban watershed rainfall and surface runoff generation to pollutant transport and pipeline operation. Particularly under scenarios of extreme rainfall and accelerated urbanization, it provides robust technical support for evaluating and optimizing urban drainage systems. In flood simulation, SWMM predicts water depth, peak flow rates, and drainage network loads based on various pavement conditions, rainfall intensity, and duration. For sponge city research, it evaluates annual runoff control rates and peak reduction effects through simulations of low-impact development (LID) facilities like permeable pavements, green roofs, and rain gardens, assisting in optimizing green infrastructure layouts. In water quality analysis, SWMM investigates initial stormwater pollution and overflow contamination processes, estimating pollutant loads such as COD, TP, and TN to provide quantitative evidence for non-point source pollution control. Additionally, the model is extensively used in engineering practices including drainage network optimization and assessment of overflow control solutions. In recent years, SWMM has continuously expanded its software functionalities, giving rise to multiple modeling platforms including PCSWMM, InfoWorks ICM, GIS-SWMM, and PySWMM. These advancements have enhanced visualization capabilities, statistical processing power, and programming interface scalability. Meanwhile, with the development of big data, remote sensing, IoT, and AI technologies, SWMM is progressively integrating with real-time monitoring and early warning systems, driving its transformation from static simulation to dynamic intelligent decision support. Despite these progressions, challenges persist such as complex model modeling, high difficulty in obtaining input parameters, and limited coupling simulation capabilities between groundwater and surface runoff. Therefore, practical applications often require combined use of GIS systems, parameter calibration tools, and data-driven methodologies to establish high-precision simulation frameworks. Overall, as a powerful, open-source, and adaptable stormwater runoff modeling tool, SWMM has become an indispensable core technology in urban drainage, water environment management, and sponge city construction. Its future development will focus on advancing towards higher integration, greater intelligence, and multi-objective collaborative simulation.

2. Research progress of swmm model at home and abroad

2.1 Domestic research progress

With the continuous advancement of urbanization, China's cities are facing increasingly severe challenges in stormwater management. Frequent occurrences of urban flooding and rainwater resource waste have made it imperative to develop scientifically effective simulation tools. The SWMM model, renowned for its open-source nature, high simulation accuracy, and broad adaptability, has gradually become a widely adopted tool for urban stormwater discharge and flood analysis in both academic research and engineering practice. In recent years, domestic scholars have conducted extensive studies on parameter sensitivity, model calibration, urban flood simulation, LID green infrastructure simulation, and integration of the model with other technologies. These efforts have significantly promoted localized applications and optimized development of the SWMM model in China's complex urban environments.

Ren Bozhi[1] et al. introduced the SWMM model principles, including surface runoff subsystem calculations, surface stormwater subsystem calculations, and transport subsystem flow calculations. Field measurements in Xianning Port Area, Changsha City verified the model's high accuracy for stormwater analysis in small watersheds, with peak flood flow relative error reaching only 7.85%, making it suitable for stormwater drainage simulation. Meng et al., (2021) validated the SWMM model's application to simulate rainfall runoff processes in karst peak cluster depressions dominated by pipelines using Guilin Yaji Experimental Site as a case study. Employing the Green-Amphoux infiltration calculation method while considering recharge from gas-bearing fractures, they calculated flow curves at the S31 Spring outlet using the SWMM model. Results showed that simulated flow patterns closely matched observed data, demonstrating the model's effectiveness in simulating rainfall runoff processes in karst peak cluster depressions. Dong Xin[3] et al. investigated stormwater runoff processes and pollutant loads in urban impermeable surfaces using SWMM modeling, focusing on roof surfaces. They applied the HSY algorithm based on uncertainty analysis and Monte Carlo sampling methods to identify and validate hydrological/hydraulic and water quality parameters. While validated parameters passed model verification, challenges persisted when simulating pollutant concentration curves during specific rainfall events. Pan and Li (2025) used SWMM to simulate drainage system operations in selected areas, proposing two pipeline improvement solutions: elevation adjustment of nodes and pipe diameter enlargement. The study significantly alleviated node overflow and pipeline overload issues. It was found that increasing pipe diameter proved to be an effective solution for mitigating these problems. Ma Xiaoyu[5] conducted research on non-point source pollution in a typical residential area of Wenzhou City, establishing a SWMM model for the study zone. Four rainfall scenarios were designed to analyze the accumulation process of suspended solids (SUS) under different rainfall conditions. Results showed that the simulated values from the SWMM model closely matched actual measurements, with relative errors for all four pollutants remaining below 10%. He Shuang[6] applied the SWMM model to simulate runoff processes at pipeline outlet sections under three LID (Landscape-Infiltration-Buffering) measure combinations in Huai 'an City's Licheng International Residential Area, Jiangsu Province. The study evaluated the stormwater control effectiveness of various LID measures. Results indicated that all measures reduced runoff coefficients, decreased peak flow rates, and delayed peak occurrence times, with combined LID measures demonstrating optimal performance under low recurrence intervals. Zhu Jing[7] developed a hydrodynamic model integrating flood control, drainage, and drainage systems using the SWMM framework, considering rapid urbanization and complex hydrological characteristics in southwestern China. The research further explored generalized subbasin aggregation methods for large-scale watershed analysis. Results demonstrated the model's applicability in southwestern China, where aggregated subbasin methods effectively reduced modeling workload while maintaining computational accuracy, facilitating broader application. Zhu Jiaqi[8] conducted sensitivity analysis of SWMM parameters using the LH-OAT method, identifying key influencing factors to guide parameter calibration. Li Chunlin[9] applied the Morris screening method to evaluate parameter sensitivities in both hydrological and water quality modules of the SWMM urban runoff model under three rainfall intensity scenarios. Results showed that rainfall intensity significantly affects infiltration parameters within the hydrological module, while having limited impact on water quality parameters. Land use patterns in the study area also substantially influence parameter sensitivity. Luan et al, (2017) utilized the SWMM model with control variable analysis to calculate permeability rates for different sizes of infiltration channel LID measures. The findings demonstrated that compensation effects increase proportionally with LID measure size, revealing a quantitative relationship between LID dimensions and permeability rates. This establishes a reliable framework for LID deployment planning and provides innovative approaches for advancing LID technology development. Yang et al., (2019) selected the old town area of Zhenjiang City as the research region, using the SWMM model to construct a drainage system model. The study simulated the operation of the pipeline network under 30-year flood conditions, focusing on severely flooded catchment areas. Four LID measures and different combinations were deployed to simulate eight scenarios for runoff control. Finally, green roof facilities were randomly installed at 20%,50%, and 80% coverage rates on building rooftops, comparing spatial-scale responses of catchment area runoff coefficients to various LID measures. Results showed that LID design schemes significantly improved sponge city rainwater management, providing references for local flood control. Arjenaki et al., (2021)developed a rainwater pipeline SWMM model based on a large-scale exhibition project case. The model results guided optimization of engineering designs while verifying compliance with planning indicators and flood risk assessments. Wang Xiao[13] proposed an orthogonal experimental design method based on global sensitivity analysis, utilizing the SWMM model at Tieshan Service Area. Results indicated that Horton's maximum infiltration rate, permeability decay coefficient, permeable zone roughness coefficient, and permeable zone depression storage significantly influenced peak runoff. The roughness coefficient in impermeable zones had significant impact on peak runoff under 5-year or longer return period rainfall conditions. Parameters related to infiltration and permeable zone depression storage also substantially affected service area runoff coefficients. Si, S. et al., (2022) utilized the SWMM model to simulate runoff processes in a city in northern China, investigating the pollution control effectiveness of low-impact development (LID) facilities such as green roofs, permeable pavements, and bioretention basins under different return periods. The results indicate that sponge city renovations can effectively mitigate runoff pollution, but their control efficacy declines with increasing return periods, suggesting that sponge cities are more suitable for controlling runoff pollution under low rainfall intensity scenarios. He, Z., et al, (2025) researched on Karst Basin in central Guizho, this study innovatively applied the SWMM model to simulate runoff generation and convergence processes in karst basins. It quantified water source transformation in sub-convergence zones and the study area, validating the model's applicability. Results indicate that the SWMM model is suitable for simulating runoff generation and convergence processes in karst basins. While demonstrating accuracy in simulating these processes and initial water source transformation, the model underperforms in depicting vegetation interception capacity and later-stage surface subsurface evaporation. Zhang Peilin[16] developed a SWMM model for the Li Lake area in Guangzhou City to analyze sponge city construction effects. Calculations through the SWMM model revealed that before low-impact development, all drainage networks overflowed under various return period rainfall conditions, with overflow rates increasing as design return periods grew. Post-development, network overflow significantly decreased across all return periods. One study revealed that SWMM model and applied modified Morris screening method and Sobol method to optimize peak flow and runoff coefficient parameters under different rainfall scenarios. The study explored parameter sensitivity distribution characteristics and compared the effectiveness of both methods. Results showed that both approaches identified high-sensitivity parameters under different objective functions, with pipeline roughness coefficient being the most sensitive parameter for peak flow under both methods. Regarding runoff coefficients, the modified Morris screening method was identified as the most sensitive parameter for determining maximum infiltration rates. This method enables qualitative prioritization of parameter sensitivity and offers efficient computational advantages, while the Sobol method provides comprehensive analysis of parameter interactions and their influencing mechanisms (Hashemi and Mahjouri, 2022). Farina et al., (2023)conducted a case study on urban drainage system design, the research applied the combined approach of the regulation algorithm and SWMM model to optimize urban drainage systems. By implementing the optimized solution in the SWMM model, dynamic simulations and analyses were performed on stormwater runoff processes. These findings provide scientific references for flood disaster prevention and drainage system improvement in the northern section of the Laoxia River area of Zhengpu Port New District, contributing to the district's development needs.

1. 2. Research progress abroad

In recent years, with the acceleration of urbanization and the growing complexity of environmental challenges, SWMM (Hydrological Modeling) has been widely adopted in global water resource management, pollution control, and flood risk assessment. Scholars worldwide have conducted in-depth research across diverse regions and application contexts, integrating multiple aspects such as model parameter optimization, hydrological-hydrodynamic coupling, climate change impacts, and green infrastructure development. These studies have provided scientific foundations and technical support for sustainable urban water environment management.

Scott A. Lowe[19] provided a detailed introduction to the application of the SWMM model in designing sanitary sewer systems for 62 proposed land development projects, explaining how to configure SWMM parameters for handling infiltration and inflow as well as basic residential sanitary flows. S.C. Lee [20] utilized the SWMM model to evaluate Annual Load Reduction (ATRL) for optimizing non-point source (NPS) pollution control in the Total Maximum Daily Load (TMDL) framework, aiming to eliminate uncertainties. The study compared annual average removal efficiency (RE) under four methodologies and recommended the Empirical Correlation Method (EMC) regression (ROE), which was deemed superior to other methods including Efficiency Ratio (ER), Total Load Sum (SOL), Load Regression (ROL), and Rainfall Frequency Method (ROF). Results demonstrated that ROE serves as an effective method for evaluating the average RE of Best Management Practices (BMPs). Kachholz Frauke[21] highlighted that evapotranspiration (ET) significantly impacts groundwater recharge and base flow, particularly in northern Germany's low-lying areas with shallow groundwater tables. To analyze this relationship, researchers developed the SWMM-UrbanEVA model, which incorporates an enhanced ET module into the traditional SWMM framework for comparative analysis. Findings revealed that conventional SWMM models overestimated total ET by 7% compared to the upgraded version, resulting in lower groundwater recharge rates and slightly underestimating base flows. The study concluded that the improved SWMM model proves more suitable for seasonal hydrological modeling in near-natural watersheds.Mohammed Maryam Hassan[22] utilized the SWMM model to analyze the impacts of climate change and flooding on the sewer system in Al-Shuhada district, Samawa City, Iraq. The system's performance before and after rainwater leakage was evaluated through different recurrence intervals (2, 5, 10, and 25 years), with manual calibration of the model (NMSE = 0.123, R = 0.86) to validate its effectiveness. Results showed that the system operated well during dry seasons but faced localized flooding risks during rainy seasons. As the recurrence interval increased from 2 years to 25 years, the sewage system's flood volume rose from 2504 m³ to 8868 m³, and the proportion of flooded inspection chambers increased from 10% to 24%. The proposal to construct two additional pipelines could effectively mitigate flooding. Overall, SWMM serves as an effective tool for assessing flood risks and verifying disaster reduction measures. Bartosz S [23] analyzed rainfall characteristics' effects on flood volume per impermeable area and overflow chamber proportions using the SWMM model combined with IDF curve parameters, while introducing the GLUE method to evaluate model uncertainties. Results indicated that model uncertainty significantly influenced certain drainage metrics, emphasizing its importance in system renovation and sustainable development decisions. Parameter sensitivity analysis revealed that the Manning coefficient had the greatest impact on flood volume, while impermeable area significantly affected the overflow chamber ratio. Altobelli M[24] proposed achieving dual objectives through the hybrid utilization of retention basins: under real-time control system (RTC) regulation, integrating rainfall forecasts and water level information ensures downstream hydraulic safety while reusing rainwater for non-potable needs. Using SWMM 5.1 to simulate 27 discharge control scenarios, the study demonstrated the hybrid system's significant potential in water conservation and drainage management. Rawas A G[25] developed a multi-stage cyclic decision-making framework for drought-prone mountainous flood areas, coordinating upstream-downstream interdependencies to optimize flood management strategies. SWMM modeling analysis showed the selected strategy could reduce urban inlet peak flood discharge by 60.7% and enhance shock absorption capacity by 81.8%. This framework breaks traditional unidirectional cascading processes, establishing a cyclic mechanism that coordinates hydrological conditions and multi-stakeholder preferences, facilitating sustainable solutions from both hydrological and socio-economic perspectives. Baida E M[26] applied the modified IDF curve to simulate 100-year floods in Zayou, northeastern Morocco, combining 2D hydrodynamic models with SWMM to evaluate NbS measures. Results indicated that river-type NbS reduced peak flood flow by 28.95%, while green infrastructure combinations decreased urban runoff by 44.7% while significantly conserving water resources. The study demonstrated NbS as an effective approach for addressing flooding and water scarcity, providing crucial references for urban planning and policy formulation. Rosa B.W.D[27] developed a SWMM-calibrated water quality model to simulate total suspended solids (TSS) and nutrient loads under various land use scenarios. The results demonstrated that existing pollution load levels could be maintained even with urban expansion, highlighting the significant emission reduction effect of Green Infrastructure (GBI). Kim J [28] analyzed the Yubridge Watershed in Ulsan, South Korea using the SWMM 5.1 model to evaluate low-impact development (LID) technologies 'effectiveness in improving water cycles. The study revealed that LID implementation in urban public areas holds substantial potential for water resource management, providing an effective pathway for sustainable urban development. Javan K [29] proposed a hybrid modeling approach integrating SWMM with multi-objective evolutionary algorithm (MOEA/D) to simultaneously optimize runoff volume, peak flow velocity, and implementation costs. Using Tehran's 11th District as a case study, four LID combination schemes were assessed and prioritized through the Analytic Hierarchy Process (TOPSIS). Results indicated this methodology offers practical tools for LID optimization and urban runoff management, providing valuable decision-making references. Aurora G [30] utilized the EPA-SWMM model to simulate intermittent water supply systems (WDS) in southern Italy, comparing simulations with field experimental data. The models closely matched measured reservoir water levels and node pressures, effectively reflecting hydraulic behaviors under different water supply patterns and demand scenarios. The research also preliminarily supports analyses on equitable water resource allocation.

Conclusion

In conclusion, existing research has fully demonstrated the applicability and advantages of the SWMM model in addressing diverse urban water environment challenges. Whether for flood risk management, pollutant load assessment, or the optimization design of low-impact development technologies and green infrastructure, SWMM effectively supports decision-making. Moving forward, integrating multi-objective optimization methods with real-time control technologies will enhance the model's accuracy and applicability, providing a more robust theoretical and practical foundation for achieving sustainable urban water system development. Nevertheless, facing new challenges such as climate change, frequent extreme weather events, and urban spatial complexity, the SWMM model still requires continuous global evolution to meet simulation demands for higher resolution, stronger real-time capabilities, and more complex coupled systems.

4 Suggestions and prospects for SWMM application

As a relatively mature model, SWMM has been successfully applied in the research of hydrology, hydrodynamics and water quality, and has important guiding significance for practical work. However, no model can solve all problems, and its application is limited. There are still many problems to be further optimized in the application process of the model.

As a crucial tool for urban hydrological and hydraulic modeling, SWMM models should expand their applications in multi-scale integration, real-time dynamic simulation, multi-objective optimization, uncertainty analysis, and green infrastructure modeling. By deepening integration with GIS, remote sensing, big data, and IoT technologies, we can enhance the timeliness and accuracy of input data while strengthening support for Low Impact Development (LID) measures, thereby serving urban stormwater management and sponge city initiatives. At the application level, standardizing model calibration and validation processes, combined with advanced optimization algorithms and uncertainty analysis methods, will improve simulation precision and decision-making reliability. Furthermore, interdisciplinary collaboration should be emphasized to reinforce its role in providing decision support for smart water management and sustainable urban development, ultimately expanding the breadth and depth of SWMM model applications.

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 **reference**

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## **Annex of Terms**

| **Abbreviation / Term** | **Full Form / Term** | **Definition** |
| --- | --- | --- |
| SWMM | Storm Water Management Model | A hydrologic and hydraulic model developed to simulate urban stormwater runoff quantity and quality. |
| EPA | Environmental Protection Agency | The United States Environmental Protection Agency, the developer of SWMM. |
| LID | Low Impact Development | An urban planning approach that uses natural processes to manage stormwater and reduce runoff impacts. |
| Sponge City | Sponge City | An urban water management concept focused on absorbing, storing, and purifying rainwater through natural means. |
| Karst | Karst | A hydrogeological landscape formed by dissolution of soluble rocks, affecting groundwater flow. |
| Infiltration | Infiltration | The process by which water on the ground surface enters the soil. |
| Rainwater Harvesting | Rainwater Harvesting | Techniques for collecting and storing rainwater for reuse to alleviate urban drainage load and supplement water supply. |
| Flood | Flood | Overflow of water beyond normal confines causing inundation and potential damage. |
| Stochastic Data Analysis | Stochastic Data Analysis | Methods for analyzing data characterized by randomness and uncertainty, often used in meteorological and hydrological modeling. |
| Hydrological Cycle | Hydrological Cycle | The continuous movement of water on, above, and below the surface of the Earth. |
| Runoff | Runoff | Portion of precipitation that flows over the land surface towards streams or drainage systems. |
| Stormwater Treatment | Stormwater Treatment | Engineering or management practices aimed at removing pollutants from stormwater before discharge. |