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A study on the application of computational models as support tools in urban flood management along the Cai Nai river in Can Tho city

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Abstract: Urbanization processes often lead to flooding issues, hindering the development of cities in Vietnam. For cities undergoing planning, initial solutions are crucial. To avoid replicating old urban structures, lacking green spaces, and missing water retention systems, this paper applies Low Impact Development (LID) solutions within the Storm Water Management Model (SWMM) framework for flood management in the new urban area along the Cai Nai River, located in the new residential area of Hung Thanh Ward, Cai Rang District, Can Tho City. The integration of SWMM with LID serves as a useful tool towards sustainable urban development, aiming for a more modern and intelligent city. This tool helps managers and investors save costs and time in selecting suitable solutions tailored to the planning characteristics of the study area, ensuring effectiveness during implementation. The paper proposes constructing two scenarios: current status and planned; comparing flow rates before and after urbanization for a major rainfall event on April 2, 2023. Subsequently, LID solutions are introduced and evaluated for effectiveness through each calculated scenario.

Keywords: Urban flooding; Cai Nai; Can Tho; SWMM; LID.

1. Introduction

The study area is located within the residential area of Hung Thanh Ward, Cai Rang District, Can Tho City. The computational scope is bordered as follows: to the Northwest: adjacent to the Can Tho River; to the Southeast: adjacent to the road leading to the Can Tho Bridge (National Highway 1A); to the Northeast: adjacent to the planned bridge and Tran Hoang Na road, and to the Southwest: adjacent to the Cai Nai Canal. The total research area is 365,740 m^2 (Figure 1).

In general, Can Tho has a tropical monsoon climate with few storms, hot and humid weather year-round, and no cold season. The rainy season lasts from May to November, and the dry season runs from December to April of the following year. The average annual temperature is around 28°C, with an average of about 2 hours of sunshine per day throughout the year. The average annual rainfall is approximately 1,600 mm, with average humidity ranging from 82% to 87%. Due to the influence of the tropical monsoon climate, Can Tho benefits from favorable temperature conditions, heat radiation regimes, and high and stable sunlight levels throughout the two seasons [1].

The river, canal, and creek network here is quite dense. The two channels adjacent to the research area, Cai Nai and Can Tho, are both influenced by the main flow of the Hau River (Figure 1), so the hydrological regime of the area is strongly affected by tidal dynamics, upstream flow, and localized rainfall patterns., upstream flow and localized rainfall patterns. The hydrological regime is distinctly divided into two seasons: the flood season from July to

December and the dry season from January to June. Rainfall is the primary source of water supply for river flow. Additionally, factors such as tides and meteorological conditions impact the flow. Tides from the East Sea penetrate deeply inland and significantly influence the hydrological regime of the delta. During the flood season, tides also contribute to increased water levels in the river system, hindering flood drainage [1].

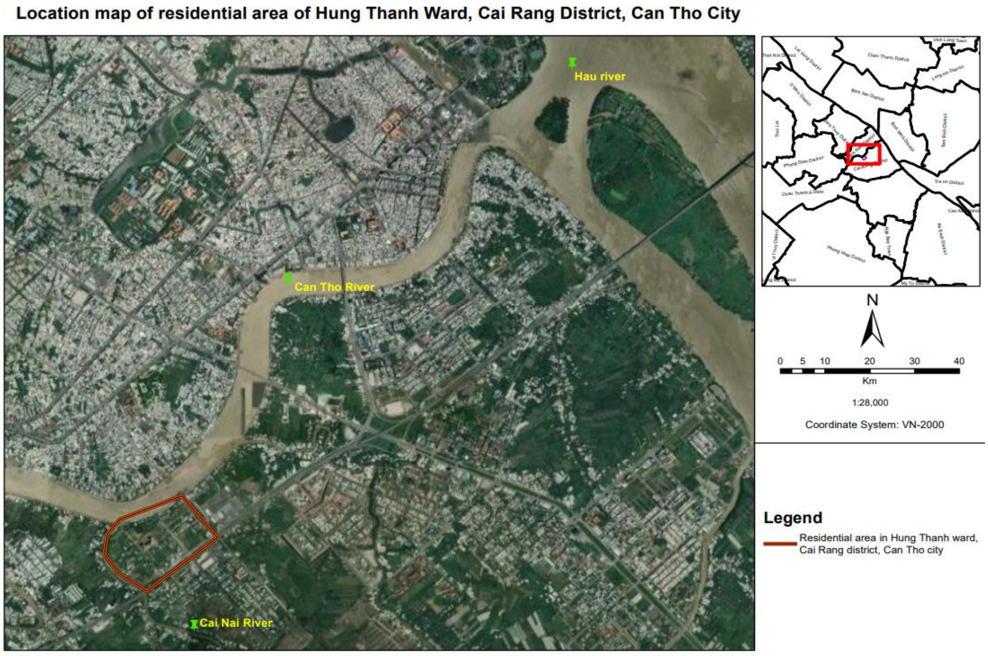


Figure 1. Location map of residential area of Hung Thanh Ward, Cai Rang District, Can Tho City.

During the land use survey, the research area is still undergoing investment planning, with a considerable amount of vacant land (Figure 2). This is why it is necessary to implement solutions to minimize flooding caused by excessive urbanization, avoiding the repetition of old urban structures, lack of green spaces, and inadequate water retention facilities. The integration of Low Impact Development (LID) with the Storm Water Management Model (SWMM) offers effective solutions suitable for the urban planning characteristics of residential areas, villas, apartments, schools, integrated areas, etc., saving costs, time in selection, and ensuring effectiveness during implementation.

Figure 2. Current land use status in the residential area.

The Storm Water Management Model (SWMM) and Low Impact Development (LID) sustainable development solutions are commonly applied in scientific research before being evaluated and implemented in practice. The studies [2,5] assess decentralized flood mitigation approaches to enhance permeability and rainwater storage capacity, addressing urban flooding issues through various structures such as green roofs, permeable pavement materials, and tree boxes, designed for different rainfall and tidal conditions. The study [3] evaluates the applicability of sustainable urban drainage solutions (SUBS) in urbanizing areas of Binh Chanh district, Ho Chi Minh City, through two scenarios: Scenario 1 enhances temporary storage capacity for rainwater reuse, while Scenario 2 reduces peak flow rates. The study [4] incorporates GIS tools to assess urban flooding in the Metro residential area of Ninh Kieu district, Can Tho province, under various urbanization scenarios.

The studies [6, 7, 9] suggest that urban expansion leads to increased impermeable areas, resulting in increased surface flow, particularly in urban and large city areas. Additionally, urban flooding is influenced by various factors such as climate, land cover characteristics, and surrounding river networks. To mitigate flood damage and control flow, these areas have developed combined LID solutions in urban stormwater management using SWMM software. Specifically, the study [6] further simulates 2.5 and 10-year recurrence cycles for two rainfall events in the city, evaluating methods to effectively reduce peak flow volumes and runoff in stormwater drainage systems. The study [8] additionally applies the Monte Carlo method to simulate annual flow processes based on LID, analyzing correlations between flow indices, peak flows, and total suspended solids (TSS) runoff. This study not only assesses reducing overflow flow but also calculates water source pollution when flooding occurs. The study [10] advances flood mitigation research methods by optimizing spatial allocation of integrated LID with SWMM using MATLAB as the platform for a residential area in Western Canada. The study [19] ues of LID in various BMP scenarios aims to minimize urban stormwater runoff and reduce pollutant load through cost-effective and environmentally friendly approaches within a modernized platform on a Python-based web framework. The outcomes yield performance metrics concerning total flow volume, pollutant loadings, and construction costs for each LID solution in every BMP scenario, resulting in a 75% reduction in overall volume control, peak flow reductions ranging from 22% to 46%, and up to 32% pollutant removal.

Overall, most LID/SUBS solutions simulated in SWMM-based studies demonstrate effectiveness in enhancing infiltration capacity, extending runoff concentration time, and reducing urban surface runoff flow.

For urban areas undergoing planning processes, particularly the new urban area along the Cai Nai River, Hung Thanh Ward, Cai Rang District, Can Tho City, initial solutions are highly imperative. To avoid replicating old urban structures lacking green spaces and water retention facilities, among other deficiencies, the application of LID solutions within the SWMM urban drainage management model serves as a valuable tool in the initial stages of design, monitoring, and technical infrastructure construction to mitigate future urban flood risks.

2. Materials and Methods

2.1. Research methodology framework

To achieve the research objectives, which involve applying LID solutions to mathematical models for urban flood management, the following research methodology framework is proposed in Figure 3:

- Conduct field investigations, site surveys, and gather relevant documents.
- Utilize correlation equations to establish a database, serving as input parameters for the SWMM urban drainage model.
- Set up the SWMM model and perform calibration and validation of the model.
- Select appropriate LID solutions and incorporate the assumptions of these solutions into the mathematical model.

- Evaluate the effectiveness of flood reduction provided by the LID solutions through two scenarios: current conditions and post-urbanization.

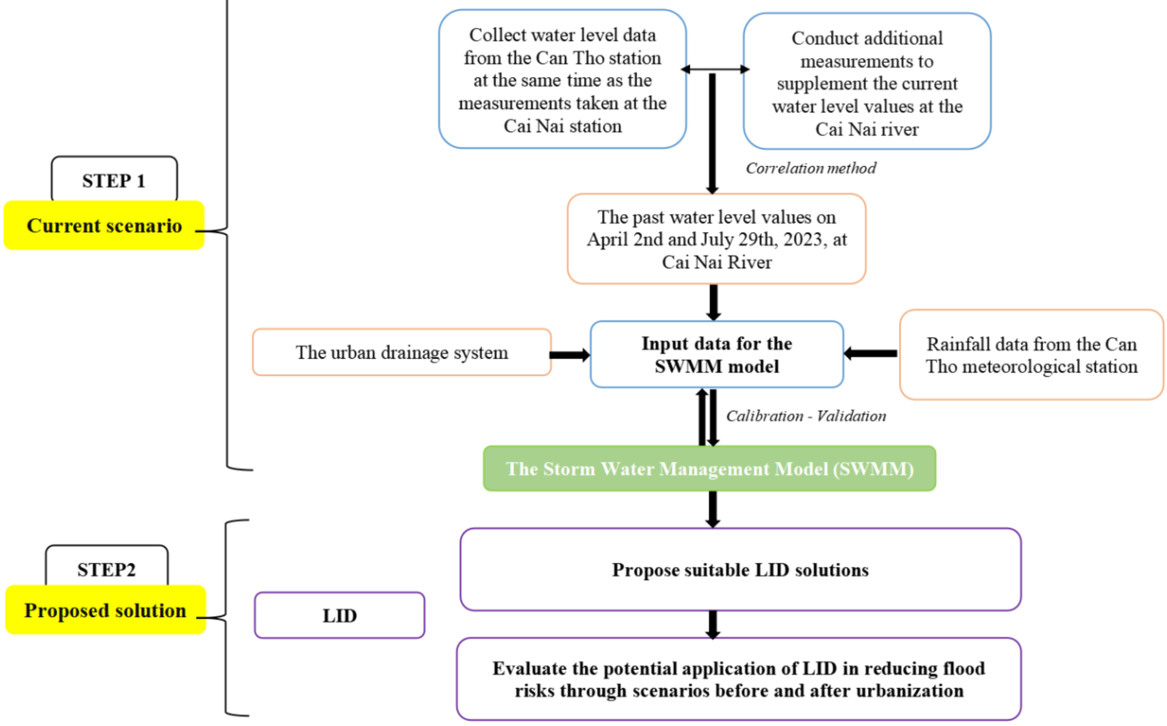


Figure 3. Research framework.

2.2. Using correlation equations to interpolate urban flooding calculation data

The research area is a newly planned residential area along the Cai Nai River, Cai Rang District, Can Tho City. To calculate the urban drainage model, it is necessary to input water level data at the urban runoff outlet. For this area, the representative water level at the runoff point is assumed to be the water level at Cai Nai, although this location does not have a hydrological station. Therefore, to ensure consistent data, the nearest hydrological station, Can Tho station (on the Hau River), was chosen to calculate and interpolate the water level at Cai Nai.

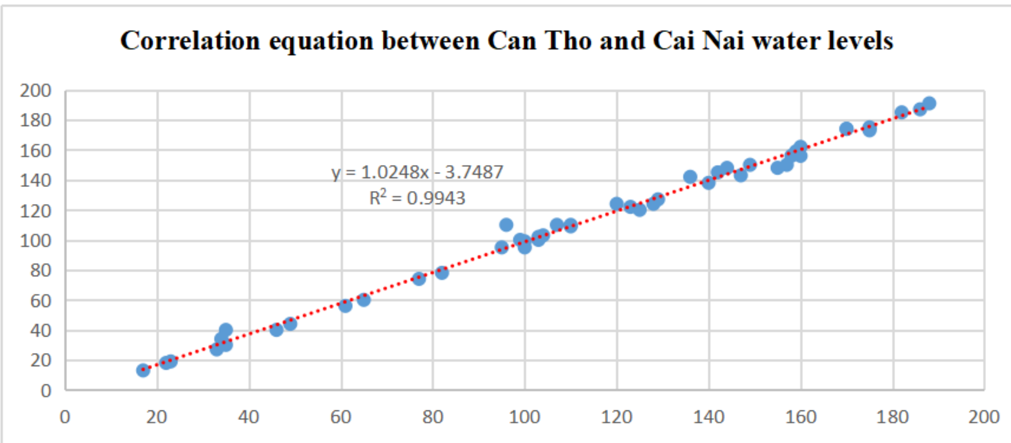


Figure 4. Correlation equation between Can Tho and Cai Nai water levels.

To find the most accurate and reliable water level values for the residential area at Rạch Cai Nai based on data from the Can Tho hydrological station, the study uses a single-variable correlation equation to interpolate water level values.

The data used in the calculation are obtained from actual measurements at the Can Tho station and a location at Cai Nai in the research area from November 1 to November 3, 2023.

A correlation equation is established based on the water level values over the three days. From this, we obtain correlated variables to support flooding calculations for past rainfall events (Figure 4).

2.3. SWMM and LID in urban water management applications

2.3.1. SWMM model (Storm Water Management Model)

The SWMM model [11, 20] (Storm Water Management Model) was developed by the United States Environmental Protection Agency (EPA) in 1971 [22] and was enhanced to Version 5.1 in 2015 [23]. EPA-SWMM is a computer program used to simulate hydrological, hydraulic, and water quality processes for both closed and open drainage networks within a watershed (urban or rural).

For the purposes of this study, the model supports dynamic simulation of rainfall-runoff processes for urban areas, calculating both the flow rates from each watershed to the outlet culvert and the inundation levels when manholes overflow.

SWMM uses a collection of nodes (manholes) and conduit segments connected through each manhole to describe the drainage network system. Additionally, this network is composed of various components: Subcatchments (watersheds), Raingages (rainfall stations), Junctions (nodes), Storage Units (detention basins), Pumps, Regulators (control valves or check valves), and Outfalls.

2.3.2. LID solutions

LID (Low-Impact Development) solutions are suitable and effective approaches in urban environmental management. Instead of constructing deep, straight drainage systems or underground sewers to quickly drain stormwater, sustainable drainage systems seek to delay stormwater runoff and consider rainwater as a valuable resource by incorporating green ecological principles with existing drainage technical principles to reduce the burden on drainage systems reasonably. The purpose of this solution is to mitigate urban flooding, replenish groundwater, minimize environmental pollution, and create green spaces in urban areas.

LID utilizes principles such as conserving and restoring natural landscape features, minimizing impervious surfaces to create a system of areas with drainage, infiltration, and treatment functions, to utilize rainfall as a resource rather than a waste. Widely applied, LID can maintain or restore the hydrological and ecological functions of watersheds. LID is regarded as a sustainable stormwater management system.

2. Setting up the storm water management model (SWMM) for urban drainage

2.1. Setting up the culvert elevations and terrain of the research area

Based on actual cross-sectional data of the Cai Nai at coordinates 10°00.089’; 105°45.810’, the current ground elevation is determined to be 2.41 meters.

From the above data, the study interpolates the elevation values of the ground, depth of manholes, and culvert bottom elevations for the

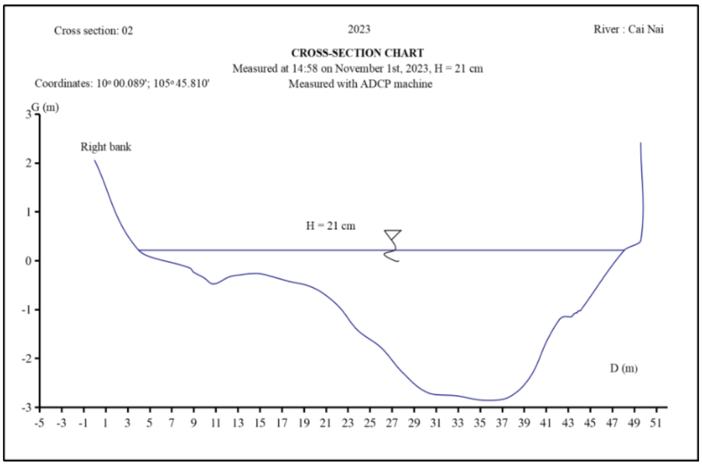


Figure 5. Cross-sectional elevation profile of the Cai Nai River.

SWMM urban drainage model, serving to calculate surface runoff and hydraulic flow in the drainage system.

2.2. Setting up the culvert, manhole, and discharge gate network

The urban stormwater drainage system consists of a combination of manholes and culverts with varying diameters designed to discharge directly into the Cai Nai at three discharge gates: CX3, CX4, and CX5. This system collects water through closed gates, arranged beneath the sidewalks, and then directs it to the river channel. Pre-cast reinforced concrete pipes with diameters of D400, D600, D800, and D1000 are used (Figure 6).

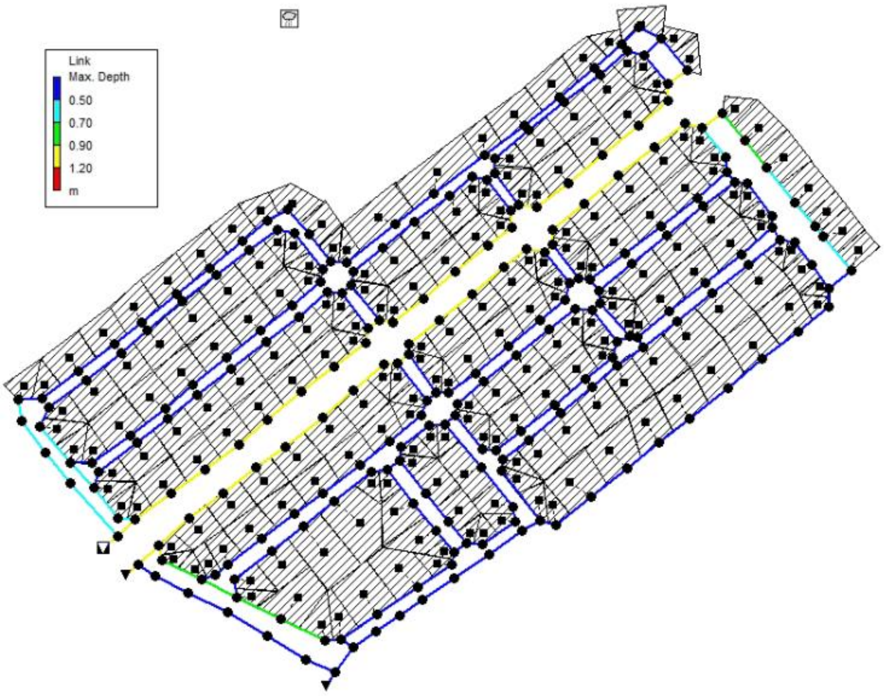


Figure 6. Dimensions of culverts and locations of manholes and discharge gates in the stormwater drainage system. (Note: Triangle symbolizes outfall, Circle symbolizes manhole).

For the culverts responsible for bearing the load, they will be designed with D = 600, 800, and 1000. The culvert with D = 1000 is the main load-bearing culvert directly connecting to the branch culvert system leading to the two main discharge gates of block 5C. The manholes and the bottom elevation of the manholes are also designed to be appropriate for the terrain of the area.

2.3. Setting up the watershed and stormwater drainage

2.3.1. Rainfall reception watershed

In the model, there are a total of 195 drainage areas, with each area linked to a corresponding manhole. The entire urban area, including (planned): 3 villa areas, 1 mixed-use area, 1 social housing area, 2 educational areas, and 3 terraced housing areas. The drainage areas in the SWMM model will be divided according to the planned development. The imperviousness percentage (%Imprev) is based on TCVN 7957:2008 standards [18].

Table 1. Impervious surface parameters.

Surface Water Drainage Characteristics	Impermeable Parameter Values (%)
Roof, Concrete Covering	0.75
Grass, Garden, Park	0.32

2.3.2. Stormwater drainage areas

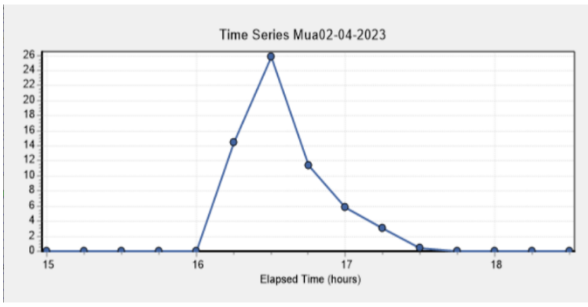
SWMM is a hydrological-hydraulic model consisting of two simulation blocks, Runoff and Extran, used to determine the relationship between rainfall and runoff, then simulate the hydraulic dynamics of flow in the drainage system. Results from the RUNOFF block (*runoff hydrograph at the rainfall reception manholes*) will serve as inputs for the EXTRAN simulation block. The EXTRAN block of SWMM uses the finite difference method with current numerical schemes to solve the 1-D Saint-Venant equation to simulate hydraulic results in the drainage system [12].

2.4. Data series used in calculation

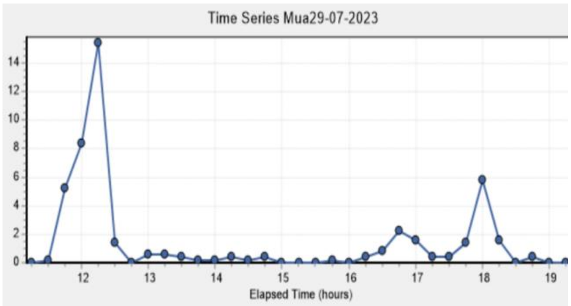
In urban drainage simulations, in addition to the rainfall runoff system and terrain of the research area, to calculate flood levels and water levels in each drainage branch, data on rainfall amounts and tidal levels at each discharge point must be input into the model. All data on rainfall amounts and water levels are collected from the Provincial Meteorological and Hydrological Station in Can Tho province.

- The rainfall amounts used in model calibration and validation are two rainfall events occurring on April 2, 2023, and July 29, 2023, with total rainfall amounts of 60.8 mm (90 minutes) and 48.8 mm (435 minutes), respectively (Figures 7a, b).

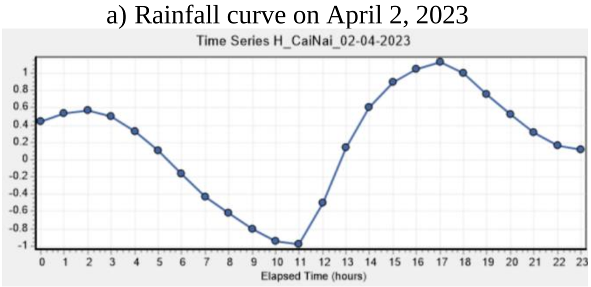
- The initial water level at each discharge point is also declared similarly for the two time points, based on the correlation equation between the water levels at the Can Tho station and Cai Nai presented in the methodology above (Figures 7c, d).



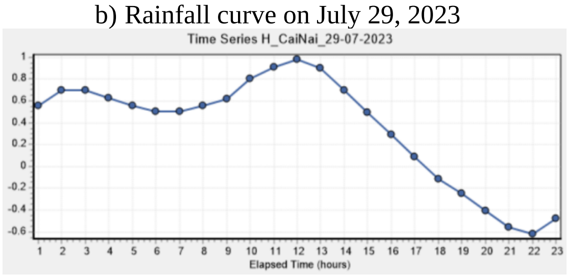
a) Rainfall curve on April 2, 2023



b) Rainfall curve on July 29, 2023



c) 24-hour water level on April 2, 2023



d) 24-hour water level on July 29, 2023

Figure 7. Input hydro-meteorological database for the model.

3. Results and solutions

3.1 Model calibration and validation

3.1.1. Model calibration

To check and calibrate the model, consider the highest flooded areas, then recalibrate with actual flood data and adjust the declared parameters such as permeability coefficient, slope, culvert elevation, manhole depth, etc. Continue to simulate again, if the results meet the requirements, proceed to check the main evaluation area of the study area. Repeat the calibration steps until we obtain a set of model parameters that closely simulate the actual results.

Table 2. Detailed results of flooding levels at manholes.

Node	Flooded CMS	Volume 106 ltr	Meter Flooding	Node	Flooded CMS	Volume 106 ltr	Meter Flooding
19c_3	0.033	0.003	0.019	9a_5	0.042	0.006	0.045
19d_3	0.041	0.004	0.025	9a_4	0.014	0.006	0.044
19d_2	0.034	0.003	0.026	19a_4	0.022	0.004	0.026
19d_1	0.012	0.003	0.024	19a_5	0.027	0.003	0.026
9a_7	0.049	0.006	0.04	19b_2	0.006	0.002	0.012
9a_6	0.038	0.006	0.044				

Figure 8. Land use status at locations of drains with water level in each manhole.

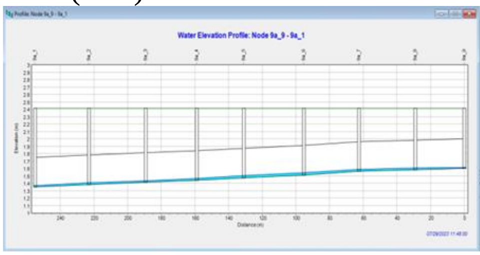
The simulation results of the flooding situation during the rainfall event on April 2, 2023, were replicated through the SWMM management model to closely match reality. According to Table 2 and Figure 6, the water level at each manhole (overflow water level) fluctuated between 0.01-0.05m; mostly concentrated in the residential areas with high-rise buildings (from node 19d_1 to 19d_3, 9a_4 to 9a_7,…).

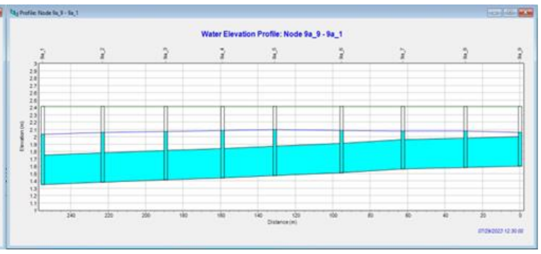
However, according to the assessment criteria for flooding from the Ministry of Construction (document 338/BXD-KTQH), a flooding depth of ≤ 0.1 m poses no risk. Based on the simulation results from the model, with values below 0.05m, the study area is evaluated as not being flooded due to heavy rain or tidal surges. This result corresponds to the data collected during the survey on the flooding situation in the area provided by residents and management.

3.1.2. Model validation

The rainfall event used to validate the model occurred on July 29, 2023, with a total rainfall of 48.8 mm lasting for 7 hours. Compared to the rainfall event on April 2 used for calibration, this rainfall event did not cause flooding. The results are presented specifically in the drainage lines to demonstrate that this rainfall did not cause manhole overflow (Figure 9). This validates the drainage lines causing flooding during the rainfall event on April 2.

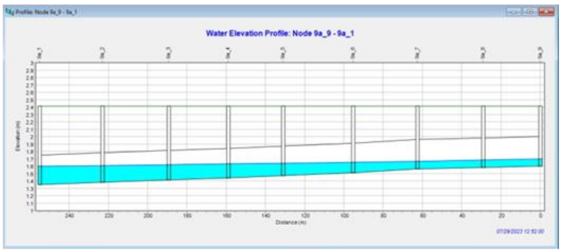
The rainfall began at 11:30 with a rainfall amount of 0.2mm; water started to appear in the drain at 11:48; peaked at 12:30 and began to recede at 12:45. Thus, with the two rain events used in model calibration and validation, reliable and close-to-reality results have been achieved. These parameter sets are further used to simulate various Low-Impact Development (LID) scenarios.





a) Time of water appearance in the conduit

b) Time of maximum water level



c) Duration of water recession

Figure 9. Water volume in the conduit during the rain event on July 29, 2023.

Furthermore, the urban area of Hung Thanh Ward, Can Tho City, along the Cai Nai River, is a newly planned area, currently undergoing infrastructure development such as housing, villas, residential areas, commercial centers, and multifunctional areas, with many vacant lots (Figure 2). Therefore, it has a good permeability and is not prone to flooding even during heavy rainfall events, unlike some older residential areas in the inner city of Can Tho [21]. The rainfall events selected on April 2nd and July 29th, 2023, are the most recent events collected during the study period and are rainfall events measured in 15-minute intervals at the Can Tho Meteorological Station. Hence, the study can only utilize these two existing rainfall events, which have been identified as having significant intensity and causing flooding in some inner-city areas of Can Tho, for simulation and model calibration.

Regarding tidal flooding, based on the collected real-world data and surveys, we have profiles showing the cross-sectional elevation of the Cai Nai River and the elevation of the bank (ground level) in the residential area (Figure 4), along with a dataset of the highest tide levels over a period of more than 40 years (1980-2023) (Figure 10). Accordingly, the bank elevation in the school area is G = 2.41m, and the maximum height H max up to the current time (2023) is 2.20 m. Based on this real-world data, it can be observed that the research area is currently not susceptible to flooding from rainfall or tidal surges.

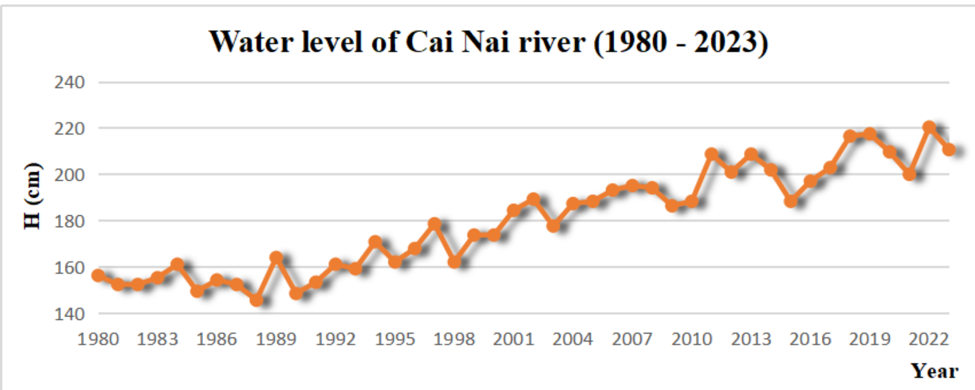


Figure 10. Water level at Cai Nai river from 1980 to 2023.

To avoid repeating the old architectural style and excessive concreteization, the study utilizes the significant rainfall event on April 2nd, 2023, along with the scenario of 100% urbanization of this new residential area to propose effective LID solutions.

3.2 Solutions to minimize urban flooding damage

LID solutions [13–17] include Bio-Retention Cell, Rain Garden, Green roof, Infiltration Trench, Permeable pavement, Rain barrel. Depending on the needs of urban planning for residential areas, integrated urban areas, these solutions are applied appropriately. For green infrastructure, the study chose to increase the watershed's permeability by 30% combined with Permeable pavement solution. This solution is implemented in parking lots, parks, parts of sidewalks, and road shoulders, etc (Figure 12).

Below (Figures 11-13) is the structure of a permeable pavement.

Benefits of Permeable Pavement:

- Effective water drainage: Helps address part of the water drainage issue during heavy rain without the need to increase the drainage capacity.

- Cost savings: Reduces costs for drainage systems while maintaining comfort and convenience.

- Moisture retention: Preserves moisture in the soil and air in the area, creating a favorable environment for plant growth.

- Economic solution: Using interlocking pavers as pavement structure may be a more economical and flexible choice compared to asphalt or concrete solutions.

The study simulated permeable pavement in reducing surface runoff, decreasing the amount of water overflowing into the drains, and increasing the time for water to accumulate in the drainage system.

The results of applying the assumed LID solution - permeable pavement - in the mathematical model show an effective reduction in the volume of runoff generated from rainfall on the surface by up to 30%

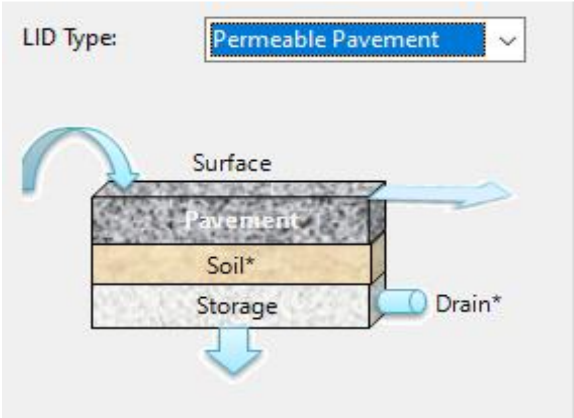


Figure 11. Structure of permeable pavement in flood mitigation support construction.

Figure 12. Example of permeable pavement structure for parking lot.

Figure 13. Some types of permeable pavement.

(Table 3). This solution also enhances the soil's permeability, thereby shortening the time for surface runoff to form in each watershed.

Table 3. Reduction rate of peak flow volume in each watershed.

Solution	Q_{max}	Peak Reduction Q (%)
Urbanization	0.3	-
Permeable pavement	0.2	30

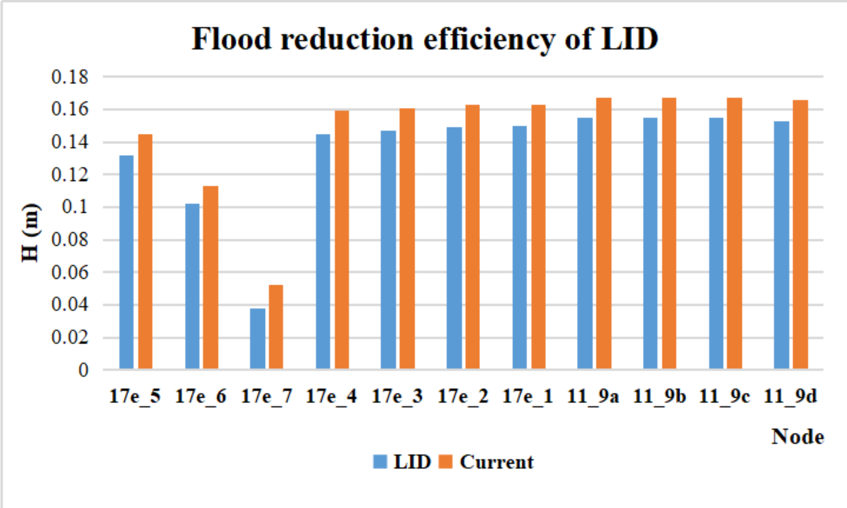


Figure 14. Effectiveness of reducing water levels at manholes.

The effectiveness of LID solutions in reducing flooding is quite promising. However, because the flooding caused by the rain event on April 2, 2023, was assessed to have only a mild impact, the overall effectiveness of this solution in reducing flooding may not be clear. Nevertheless, in general, based on the statistical data in Table 3 and Figure 14, we can observe a significant reduction in the flow volume to each manhole.

4. Conclusion

LID and SWMM in stormwater management offer long-term sustainability, economic efficiency, and provide a foundation for urban development in a positive direction, adapting to climate change. Regarding the assumed LID solutions for watersheds prone to flooding due to heavy rain, they have shown good effectiveness, serving flood mitigation for constructions, especially as these solutions have high sustainability and are suitable for urbanization processes while still ensuring flood prevention. The comparison of total water volume to each manhole between two scenarios before and after urbanization with LID implementation has significantly reduced the flow to each manhole.

However, because the research area is still in the planning stage of urban development and lacks specific designs, the integration of LID solutions to assess enhancement has limited basis for implementation.

The issue of selecting rainfall events causing flooding in this urban area is addressed in the model calibration and validation section. As this is a newly planned urban area in the development phase, with vacant land and good permeability, it does not experience flooding due to rainfall. Regarding tidal flooding, the elevation adjustments ensure no flooding occurs. Therefore, when selecting flood-causing rainfall events to assess the accuracy of the model, the author only chose two existing rainfall events that were evaluated to cause significant flooding in some neighboring areas of Can Tho City.

Author contribution statement: Developing research ideas: N.V.H.; Process data: processing, manuscript writing: N.T.H.; Set up and run the model: N.V.H., N.T.H.; Reviewed and completed the manuscript: N.V.H.

Competing interest statement: The authors declare no conflict of interest.

Reference

1. Technology Transfer Center, Southern Branch, Thuy Loi University. Project for Upgrading and Renovating the Bun Xang Regulating Lake - Can Tho City. 2015.
2. Hai, D.M. The effect of design storm characteristics on low-impact development practices for rainfall run off control. *J. Water Resour. Environ. Eng*. **2020**, *68*, 98–106.
3. Lan, N.T.M.; Dung, D.T.; Quang, C.N.X.; Giang, N.N.H. Assessing the applicability of sustainable urban drainage systems in Binh Chanh district, Ho Chi Minh city. *J. Hydro-Meteorol*. **2021**, *732*, 49–64.
4. Ngan, N.T.; Trung, N.H. Application of GIS and SWMM model to assess urban flooding in Metro Residential area of Ninh Kieu district. *Earth Environ. Sci*. **2023**, *1170*, 1–8.
5. Hieu, N.N.; Tu, T.T.; Hoa, H.V.; Nam, T.H. Evaluating approaches to dispersed flood reduction in urbanized low-lying areas on the periphery of HCMC. *Builder* **2019**, *327-328*, 1–21.
6. Majid, O.A.; Sanayei, H.R.Z.; Heidarzadeh, H.; Mahabadi, N.A. Modeling and investigating the effect of the LID methods on collection network of urban runoff using the SWMM model (case study: Shahrekord city). *Model. Earth Syst. Enviro.* **2020**, *7*, 1–16.
7. Luan, Q.; Fu, X.; Song, C.; Wang, H.; Liu, J.; Wang, Y. Runoff effect evaluation of LID through SWMM in typical mountainous, low-lying urban areas: A case study in China. *Water* **2017**, *9(6)*, 439.
8. Zhang, Z.; Hu, W.; Wang, W.; Zhou, J.; Liu, D.; Qi, X.; Zhao, X. The hydrological effect and uncertainty assessment by runoff indicators based on SWMM for various LID facilities. *J. Hydrol*. **2022**, *613*, 128418.
9. Taji, S.G.; Regulwar, D.G. LID coupled design of drainage model using GIS and SWMM. *J. Hydraul. Eng*. **2021**, *27*, 376–389.
10. Yu, Y.; et al. A new LID spatial allocation optimization system at neighborhood scale: Integrated SWMM with PICEA-g using MATLAB as the platform. *Sci. Total Environ*. **2022**, *831*, 154843.
11. Binh, C.T. Feasibility assessment of sustainable stormwater management system planning for Long Thanh High-Tech Industrial Zone - Dong Nai. 2018.
12. IGIP and WACC-ARCASIA JV. Pilot implementation of Efficient Management Model (BMP) adapted to climate change in the central area of Soc Trang city, Soc Trang province. 2016.
13. Carter, T.; Butler, C. Ecological impacts of replacing traditional roofs with green roofs in two urban areas. *Cities Environ*. **2008**, *1(2)*, 9.
14. Mentens, J.; Raes, D.; Hermy, M. Dirk Raes and Department, Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century. *Landscape Urban Plan*. **2006**, *77*, 217–226.
15. De Oliveira, E.W.N.; da Silva, L.P.; Mary, W. Telhados verdes para habitações de interesse social: retenção das águas pluviais e conforto térmico. *Universidade do Estado do Rio de Janeiro*, **2009**, *18*.
16. Hoffmann, B.; et al. Sustainable urban drainage systems. Sustainable Urban Drainage Systems, 2016, pp. 20.
17. Zhang, L.; Ye, Z.; Shibata, S. Assessment of rain garden effects for the management of urban storm runoff in Japan. *Sustainability* **2020**, *12(23)*, 9982.

18. National Standard (TCVN 7957:2008). Drainage - Networks and external structures - Design standards
19. Xu, T.; Jia, H.; Wang, Z.; Xuhui Mao & Changqing Xu. SWMM-based methodology for block-scale LID-BMPs planning based on site-scale multi-objective optimization: A case study in Tianjin. *Front. Environ. Sci. Eng.* **2017**, *11*, 1. https://doi.org/10.1007/s11783-017-0934-6.
20. Huong, N.T.T. Application of SWMM model for planning stormwater drainage to prevent flooding for Phuoc Kien, Phuoc Loc, Long Thoi, Nhon Duc communes - Nha Be district. *J. Sci. Technol. Ton Duc Thang Univ.* **2015**.
21. Can Tho: Heavy off-season rain relieves heat after many hot days. Internet: Heavy off-season rain relieves heat after many hot days. Vietnam+ (VietnamPlus), 2023.
22. Park, J.; Yoo, Y.; Park, Y.; Yoon, H.; Kim, J.; Park, Y.; Jeon, J.H.; Lim, K.J. Analysis of runoff reduction with LID adoption using the SWMM. *J. Korean Soc. Water Qual.* **2008**, *24(6)*, 805–815.
23. Rossman, L.A. Stom water management model user's manual version 5.1. United States Evironment Protection Agency, United States, 2015, pp. 353.