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Flood Mapping of the Core Urban Area of Can Tho City Using Hydraulic Modeling

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Abstract This study investigates the current flood status in the core urban area of Can Tho City, located in the Mekong Delta (Vietnam), through the application of integrated one-dimensional (1D) and two-dimensional (2D) hydraulic modeling. Utilizing detailed topographic data derived from LiDAR, alongside hydrological and hydraulic data including precipitation, land use, and drainage infrastructure. The research developed a comprehensive model to simulate flood inundation under various scenarios. The 1D MIKE 11 HD model was employed for the Mekong Delta region and provided boundary conditions for the more detailed 2D model of the Can Tho urban core. The 2D model, incorporated the city's flood protection system, was calibrated and validated using historical flood data including the significant 2018 flood event. The validated model was then used to simulate flood scenarios with recurrence intervals of 5, 20, 50, and 100 years, resulting in detailed flood inundation maps. The findings provide one of the first assessments of residual flood risk following the 2023 operational launch of the Can Tho Tide Wall System. Results demonstrate that while the system mitigates tidal flooding in the protected core, significant areas, particularly in the North-West, remain highly vulnerable to deep inundation (>1.0 m) during extreme events. The study provides spatially explicit data crucial for prioritizing secondary flood defense investments and revising land-use zoning in newly identified high-risk zones.

Keywords: urban, hydraulic modelling, inundation, GIS, mapping, flood

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1. INTRODUCTION

The escalating risk of urban flooding is a growing global concern, primarily attributed to the impacts of climate change, rapid urbanization, and the deterioration of drainage infrastructure (Development Workshop, 2011; Gaurkhede et al., 2021; Shahriar & Roy, 2024; Tyler et al., 2017). Low-lying deltaic regions, such as the Mekong Delta in Vietnam, are particularly susceptible to increasing flood severity due to their low topography, tidal influences, and the heightened frequency of extreme weather events (Tyler et al., 2017). Flooding represents one of the most significant environmental challenges impacting this downstream region(Do Thi Chinh et al., 2016). The Mekong River, often referred to as the Mother River of the delta, serves as both the lifeblood for Southeast Asia's largest rice bowl and a source of considerable negative impacts on the lives of riverside communities. While providing essential water resources and fertile alluvial deposits crucial for the Mekong Delta, the river also profoundly affects the living environment of coastal inhabitants, particularly within urban centers situated along its banks (Huynh et al., 2020).

These urban areas currently face substantial challenges related to urban flooding, primarily driven by the Mekong River's flood regime (Takagi et al., 2014). Can Tho City, the central hub and a significant economic and transportation nexus within the Mekong Delta, exemplifies the severity of urban inundation. In recent years, the city has experienced intensified flooding affecting both stormwater drainage and its internal river systems (Takagi et al., 2016). Annually, between September and December, coinciding with peak tidal water levels, the city, especially its core urban area, confronts flood events where water levels can reach up to 60 cm or more in the most deeply affected locations (Takagi et al., 2016). This recurring, prolonged seasonal inundation has resulted in substantial socio-economic consequences, including significant economic losses, damage to infrastructure, disruption of economic activities, and adverse effects on livelihoods and the well-being of its residents (Chea et al., 2016; Rajesh, 2016). Furthermore, these events lead to detrimental effects on environmental quality, notably water quality degradation (Nguyễn Hồng Quân, Radhakrishnan, et al., 2017). Consequently, assessing the flood regime within Can Tho's urban area is considered a critical initial step for subsequent research and the design of effective measures aimed at preventing and mitigating the impacts of flooding.

In the study and assessment of flood regimes, various methodologies have been employed across diverse conditions. These approaches can be broadly categorized into three main groups: field surveys, satellite data-based flood zoning, and flood modeling. The direct survey method is utilized in nearly all flood-prone areas globally (Armenakis & Nirupama, 2014; Dottori et al., 2016). It stands as the simplest and most pragmatic approach, often serving as the primary source of verification and calibration data for other model-based flood assessment methods. This method relies on direct observation and measurement of flood characteristics, such as water depth and extent, providing essential ground-truth information (Al-Abadi & Pradhan, 2020; Schumann et al., 2018; Tehrany & Jones, 2013; National Research Council, 2009). Alongside direct surveys, methods involving flood zoning and the creation of flood maps using remote sensing are also widely applied, particularly evident in research over the past decade

incorporating ultra-high frequency Synthetic Aperture Radar (SAR) data (Askar et al., 2022; Kalantar et al., 2021; Razavi-Termeh et al., 2023). However, a significant limitation of this satellite-based approach is the challenge of ensuring data capture at the precise "right time and right place" during complex, rapidly evolving flood events, especially for developing countries where financial resources for data access remain constrained (Rahman & Thakur, 2018).

The most frequently employed method for assessing flood regimes within hydrological research involves various forms of modeling, including hydraulic models, Geographic Information System (GIS) based models, and machine learning/artificial intelligence models (Gautam & Dugar, 2019; Kalantar et al., 2021). This approach leverages observational data from field investigations, earth observation data (like high-resolution DEMs derived from LiDAR), and spatial datasets to simulate and reconstruct flood-prone areas, hydrological regimes, and the dynamic processes of inundation (Youssef & Hegab, 2019; Zeleňáková et al., 2019). Processed data within these models generate outputs such as inundation maps , temporal flood progression analyses, and key flood parameters including inundation depth, flow velocity, duration, and evolution. Hydraulic modeling, in particular, employing advanced computational tools and techniques, plays a pivotal role in simulating complex flow regimes, assessing flood hazards, evaluating flood risk, and supporting the development of effective management strategies in urban environments (Abebe et al., 2019; Ben Khalfallah & Saidi, 2018; Zhang et al., 2020). The application of both one-dimensional (1D) and two-dimensional (2D) hydraulic models offers distinct advantages, enabling comprehensive simulation of in-channel flow (1D) and overland flow propagation across the terrain surface (2D) (Kuhanestani et al., 2022; Leandro et al., 2011). While modeling offers significant advantages, its application faces considerable challenges in developing nations like Vietnam, often due to low accuracy, outdated nature, or unavailability of fundamental baseline data required for robust model development and calibration (Duong & Gourbesville, 2016).

This study focuses on the development of an integrated 1D-2D hydraulic model to assess the current flood status within the core urban area of Can Tho City. This involves the simulation of various flood scenarios based on the recurrence intervals of combined precipitation and tidal events. The primary objective of this research is to provide scientifically grounded information and detailed flood inundation maps to support urban planning, infrastructure development, and the implementation of effective flood risk management measures in Can Tho City.

While numerous studies have modeled flood risk in Can Tho (e.g., Takagi et al., 2016; Do Thi Chinh et al., 2016), they predate the construction and operation of the city's comprehensive tide wall system, which was first tested in late 2023. The effectiveness of this major infrastructure intervention under various extreme event scenarios has not yet been quantified. This study fills this critical gap by developing an integrated 1D-2D hydraulic model that explicitly incorporates the new tide wall system. By simulating flood depths for 5- to 100-year return periods, we aim to move beyond a general risk assessment to identify specific areas of remaining vulnerability and provide targeted, evidence-based recommendations for the next phase of Can Tho's disaster risk management strategy.

2. STUDY AREA AND DATA

2.1 Study Area

The core urban area of Can Tho City is situated in the central region of the Mekong Delta, characterized by a low-lying topography, an intricate network of rivers, canals, and direct exposure to tidal influences from the East Sea (Nguyễn Hồng Quân, Huỳnh Thị Thảo Nguyên, et al., 2017; Tyler et al., 2017) The area encompasses approximately 3400 hectares. To ensure the accuracy of the hydraulic model, the model domain was extended to adjacent areas, specifically the Binh Thuy River to the north; the Cai Son canal, Muong Khai ditch to the west; the Khai Luong river to the east, and the Can Tho River to the south, as in Figure 1. This expanded model extent is crucial for comprehensively capturing the hydraulic factors influencing flood conditions within the core urban area, particularly the interaction with the surrounding river system and the impact of tidal dynamics.

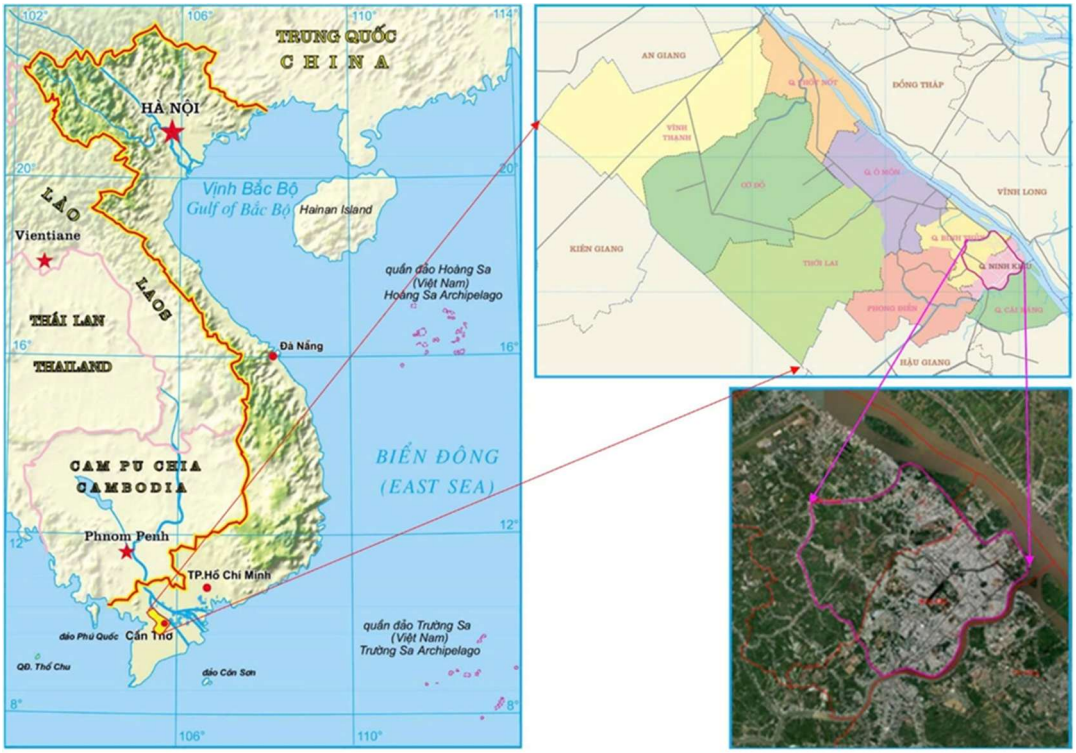

Figure 1. Core city area and model area of urban Can Tho city

The Can Tho Tide Wall System (Figure 2) is a critical urban flood protection and climate adaptation infrastructure located in Can Tho City, the economic and administrative hub of Vietnam's Mekong Delta. As one of the cities most vulnerable to the impacts of climate change, sea-level rise, and tidal flooding, Can Tho has invested in a comprehensive tide wall system to reduce the risks associated with seasonal high tides, storm surges, and heavy rainfall. This system is composed of reinforced embankments, tide gates, sluice systems, and pumping stations, strategically constructed along key riverbanks and low-lying urban areas. The tide gates are designed to automatically close during high tide to prevent river water from overflowing into residential zones, while the pumping stations help drain rainwater during

heavy storms, ensuring that both fluvial and pluvial flood risks are managed (People Committee of Can Tho city, 2015; World Bank Group, 2014).

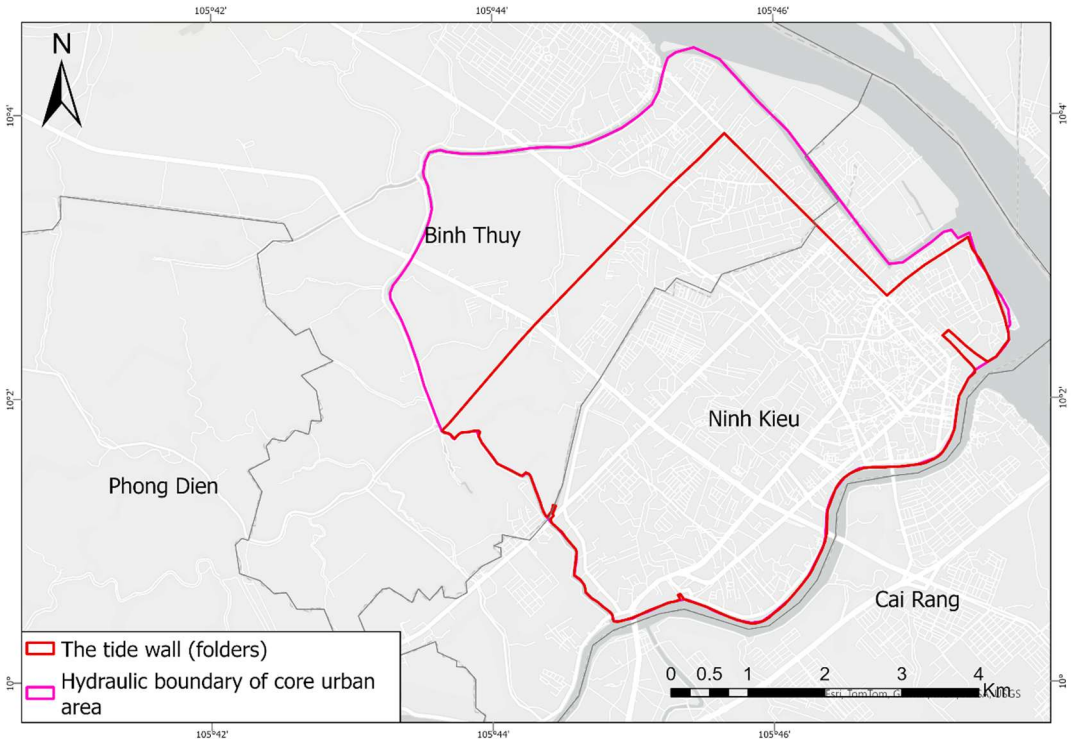

Figure 2. The tide-wall system of Can Tho City

2.2 Data Acquisition

The hydraulic model was developed using several key datasets sourced from local authorities and utility providers.

- **Topographic Data:** The primary layer was a 5-meter resolution Digital Elevation Model (DEM) from a 2011 LiDAR survey—the most recent, high-precision data available for the area. This was supplemented by a 1/5000 scale topographic map to define the 2D overland flow domain. Potential uncertainties arising from the DEM's age, such as uncaptured urban development and land subsidence, are acknowledged.

- **Hydrological Data:** Inputs for the rainfall-runoff model included contemporary land use maps to define surface runoff coefficients and temporal precipitation data from the Can Tho meteorological station.

- **Hydraulic Data:** The model incorporated detailed infrastructure data, including the drainage network geometry (pipes, manholes, outlets) from the Can Tho Water Supply and Sewerage Joint Stock Company (WASSCO) and the open channel network (schematics, cross-sections, lake bathymetry) for the 1D model.

3. METHODOLOGY

The process of determining the flood status in the core urban area of Can Tho City was conducted through four primary steps as presented in Figure 3.

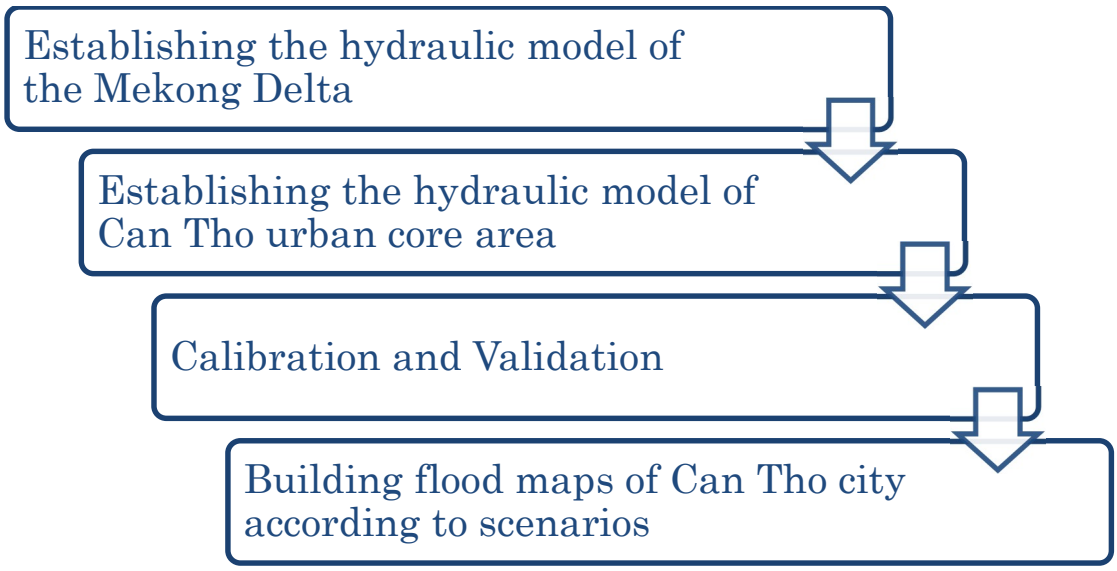

Figure 3. The process of determining flood status in the core urban area of Can Tho City

The initial step involved the development of a 1D hydrodynamic model for the entire Mekong Delta, utilizing the MIKE 11 HD module, a widely recognized one-dimensional hydraulic modeling software developed by Danish Hydraulic Institute (DHI). This model simulates flow and water levels at four upstream stations and 57 downstream stations, encompassing the major rivers and canals within the Mekong Delta region. The output data from this model were processed to determine water levels in the Hau River and the surrounding rivers, canals in the core urban area of Can Tho City. The Mekong Delta model was developed, updated, and recalibrated by the "Disaster Mitigation Project (WB4)" using the 2018 flood event, ensuring the model's relevance to recent hydrological conditions in the region. The utilization of a pre-existing and calibrated regional model enhances efficiency, ensures consistency with regional hydrological processes.

The second step entailed the establishment of a 2D "overland flow" model for the core urban area. This model utilized the water level boundaries determined in the first step from the 1D Mekong Delta model. Detailed data on topography (from the LiDAR DEM and 1/5000 scale map), land use, precipitation, the drainage system, and the flood protection system were incorporated into the 2D model to simulate potential flood scenarios. The 2D model allows for the simulation of floodwater propagation across the complex terrain of the urban area.

The third step involved the calibration and validation of the 2D model for the core urban area using real-world data. This is a critical step to ensure the model's accuracy in representing actual conditions [33]. Calibration data may include information on flood extent and depth reported by WASSCO, as well as water level data from the 2018 flood event on the Hau River.

The calibration process involves adjusting model parameters (e.g., Manning's roughness coefficient) to minimize discrepancies between simulated results and observed data. Following calibration, the model needs to be validated using an independent dataset to assess its predictive capability.

The final step involved running the calibrated and validated 2D model with various scenarios. Input parameters for these scenarios included combined conditions of precipitation and tidal water levels, representing recurrence intervals of 5 years (20%), 10 years (10%), 20 years (5%), 50 years (2%), and 100 years (1%). The output data from these simulations were used to generate flood inundation maps for the core urban area of Can Tho City, enabling the assessment of flood risk at different probability levels.

3.1 Hydraulic Model Development

3.1.1 Mekong Delta Model (1D)

The one-dimensional (1D) hydraulic model for the Mekong Delta was developed and updated using the MIKE 11 HD module of the MIKE 11 software package, a robust modeling system developed by DHI for simulating flow, water quality, and sediment transport in rivers, canals, estuaries, and other inland water bodies. This model was previously developed and updated by the "Disaster Mitigation Project (WB4)" and recalibrated with the 2018 flood event ensuring its reflection of recent hydrological conditions in the region as presented in Figure 4.

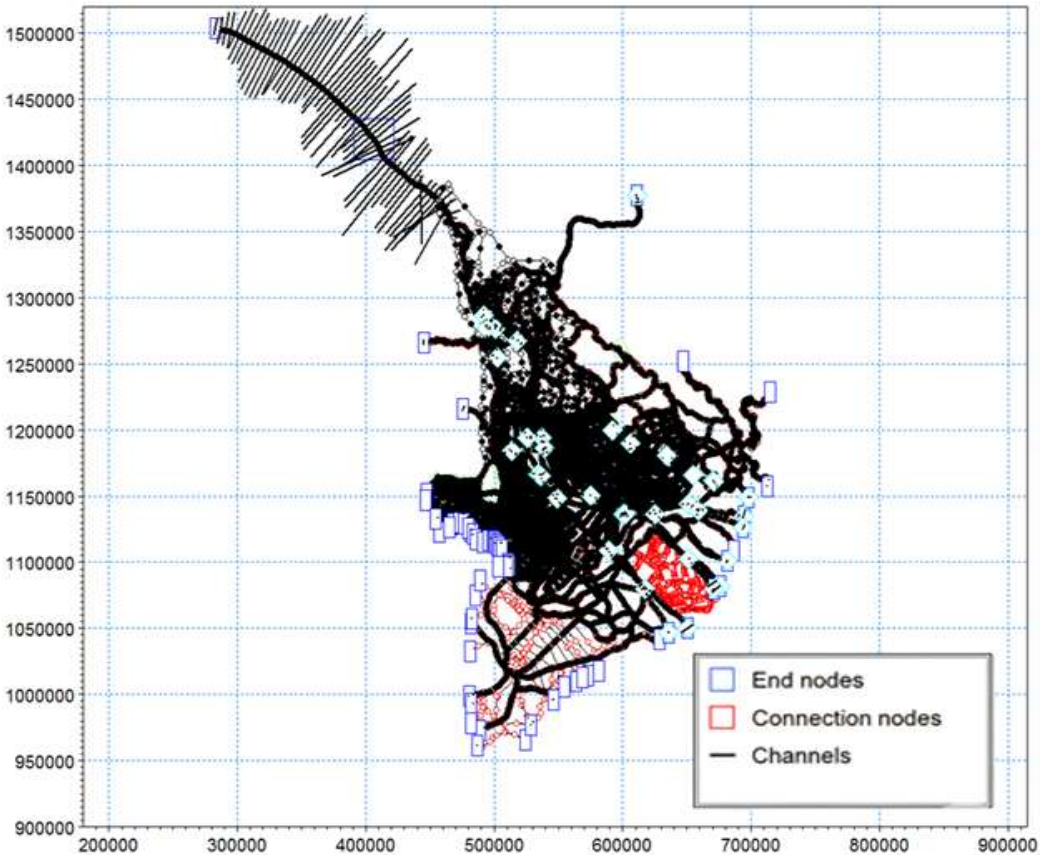

Figure 4. Mekong Delta Model (From WB4 project)

The Mekong Delta model encompasses a vast area, extending from Kratie and the Tonle Sap upstream to the East Sea and Thailand Bay downstream. The complex network of rivers and canals within the delta is simulated in detail within the model. The model's boundary conditions include four upstream flow boundaries (Tonle Sap, Kratie, Dau Tieng, Tri An) and 57 downstream tidal water level boundaries. These downstream boundaries include major rivers such as the Long Tau, Vam Co, Mekong, Cua Dai, Ba Lai, Ham Luong, Co Chien, Hau (Bassac), Tran De, My Thanh, and several water boundaries along canals in Ca Mau and Kien Giang peninsula. The inclusion of numerous tidal boundaries downstream highlights the significance of accurately modeling tidal influence on the delta's hydrological system.

Calibration

As illustrated in Figure 5, Figure 6, and Figure 7, the result is acceptable. The simulation profiles in some control sections along the Hau River fit the observed profiles sufficiently. The values of performance indicators are also statistically significant as presented in Table 1.

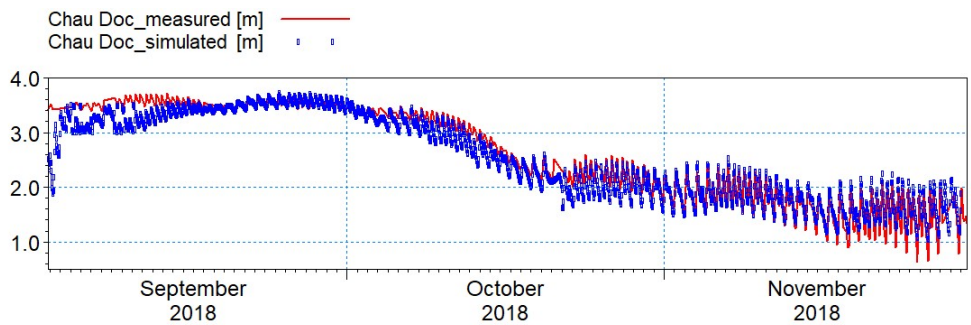

Figure 5. Comparison of the observed and simulated water level at Chau Doc station

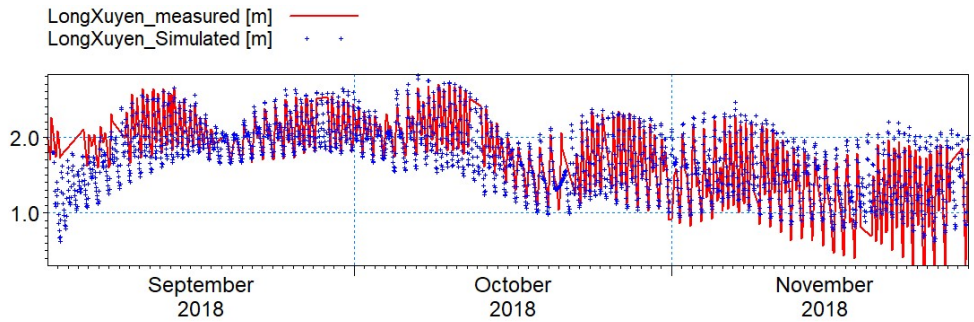

Figure 6. Comparison of the observed and simulated water level at Long Xuyen station

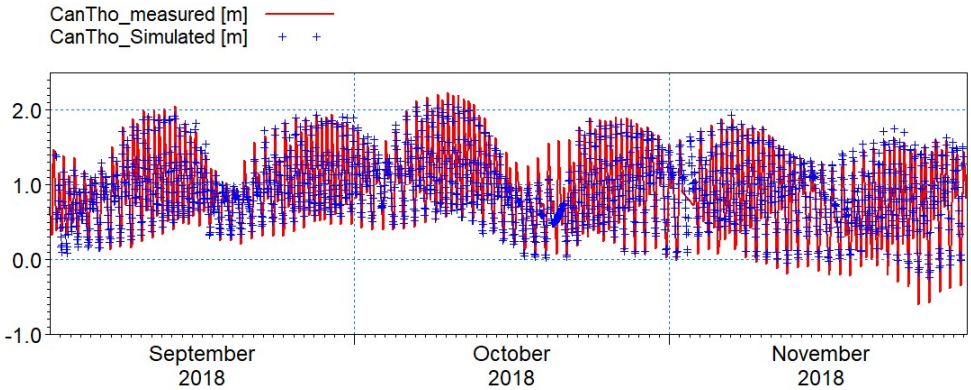

Figure 7. Comparison of the observed and simulated water level at Can Tho station

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Table 1. Indicators at 3 water level stations

Indicators	Long Xuyen	Chau Doc	Can Tho
NSE	0.65	0.96	0.91
	Good	Very good	Very good
RSR	0.59	0.19	0.30
	Good	Very good	Very good

Validation

The validation results are shown and compared with the recorded data in Figures 8, 9, and 10, applying the parameter set of the calibration phase. The observed water level data at Can Tho, Chau Doc, and Long Xuyen stations in the flood season of 2011 were collected. The values of performance indicators are good as presented in Table 2.

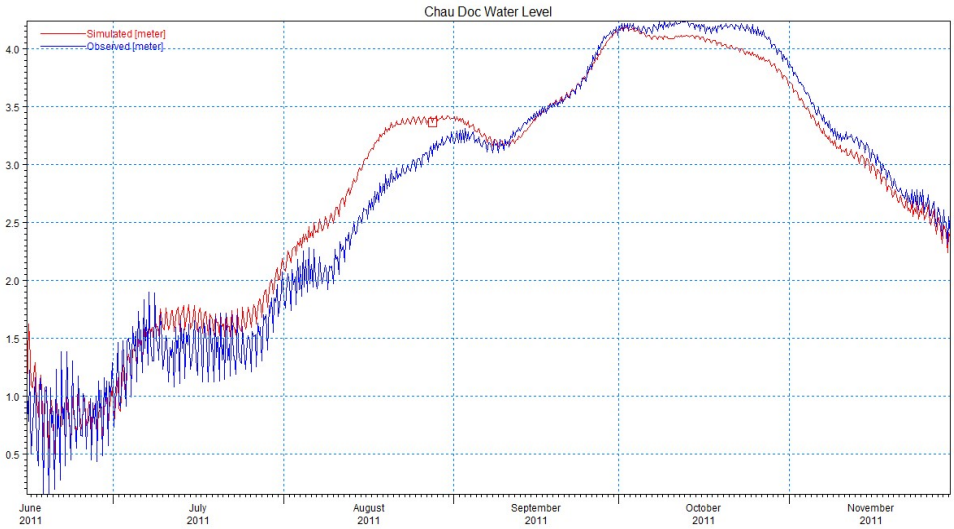

Figure 8. Observed water level at Chau Doc station in the flood season of 2011

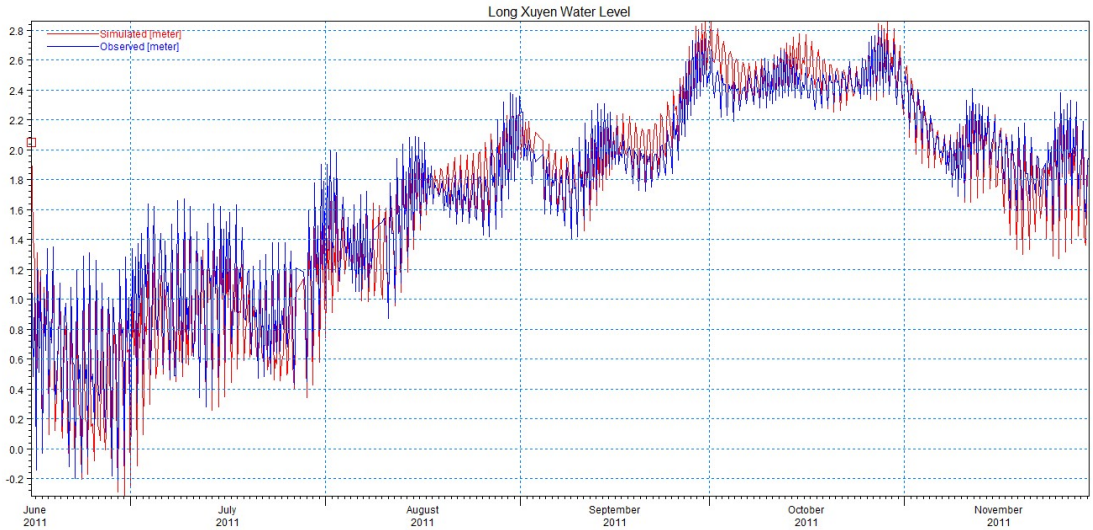

Figure 9. Observed water level (red) and simulated ones (blue) at Long Xuyen station in the flood season of 2011

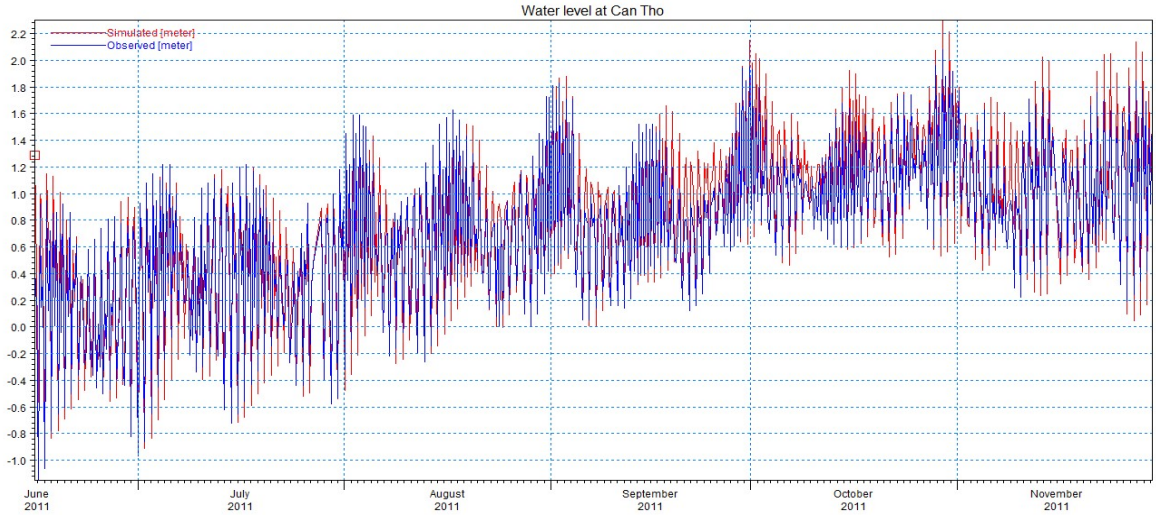

Figure 10. Observed water level (red) and simulated ones (blue) at Can Tho station in the flood season of 2011

Table 2. Performance indicators and their rating

Indicators	Long Xuyen	Chau Doc	Can Tho
NSE	0.95 Very good	0.90 Very good	0.98 Very good
RSR	0.23 Very good	0.31 Very good	0.23 Very good

3.1.2 Core Urban Area Model (2D)

The core urban area of Can Tho City is located in the Mekong Delta model domain, shows in Figure 1. The integrated model for this case study was derived from the broader Mekong Delta model. The Can Tho core urban area model was initially developed entirely from raw data and subsequently calibrated using recorded extreme events such as storm surges and heavy rainfall leading to flooding. The spatial extent of this model is illustrated in Figure 11. Following simulations with the Mekong Delta model, the boundary conditions for the core urban area model were extracted from the Mekong Delta model results, ensuring consistency between the regional and local models.

The water level boundaries were set at five points along the Binh Thuy, Can Tho, and Khai Luong rivers (BC1–BC5), as shown in Figure 12.

Boundary BC4, located near the Can Tho gauging station on the Hau River, was considered equivalent to the observed or forecasted Hau River water level provided by NCHMF. During calibration and validation, boundary water levels were derived from the 1D Mekong Delta model, which showed a strong correlation between BC4 and other boundaries (Figure 13, Figure 14). Hence, empirical relationships between BC4 and BC1–BC5 were established and applied in scenario simulations to define the dynamic boundary conditions of the model.

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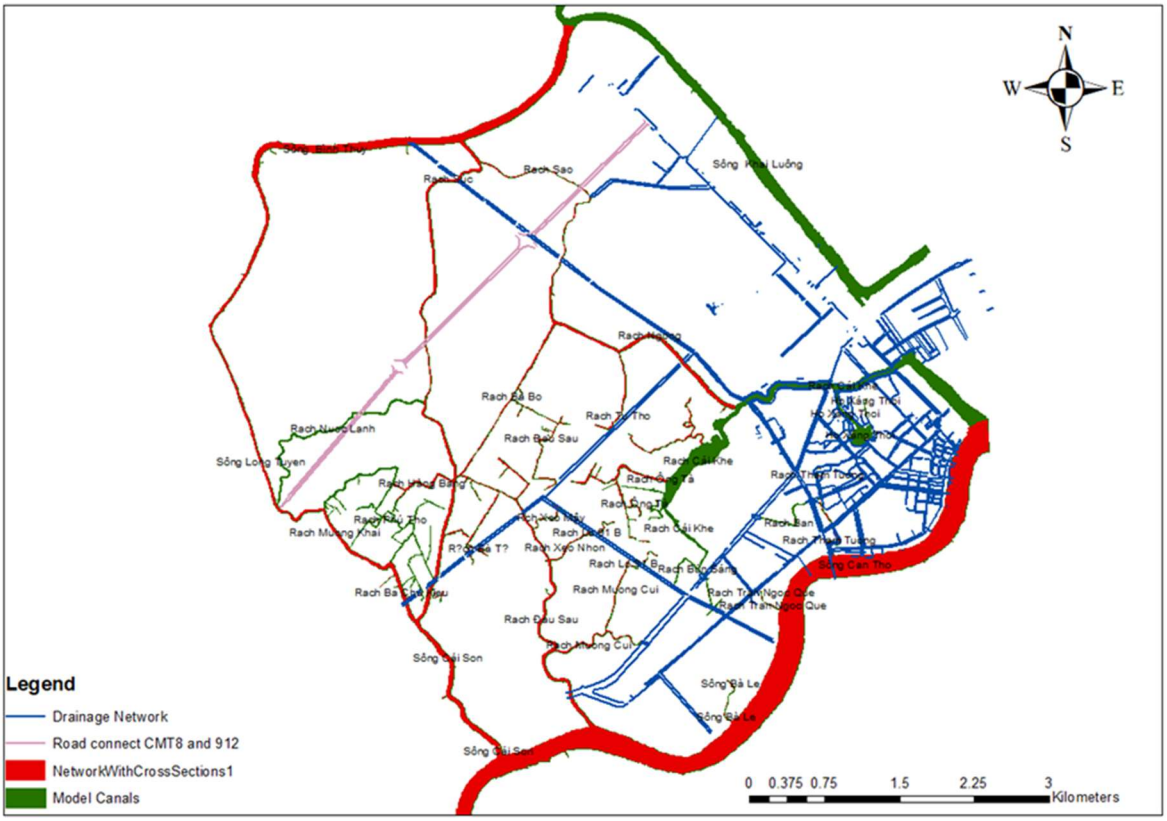

Figure 11. The core urban area of Can Tho city

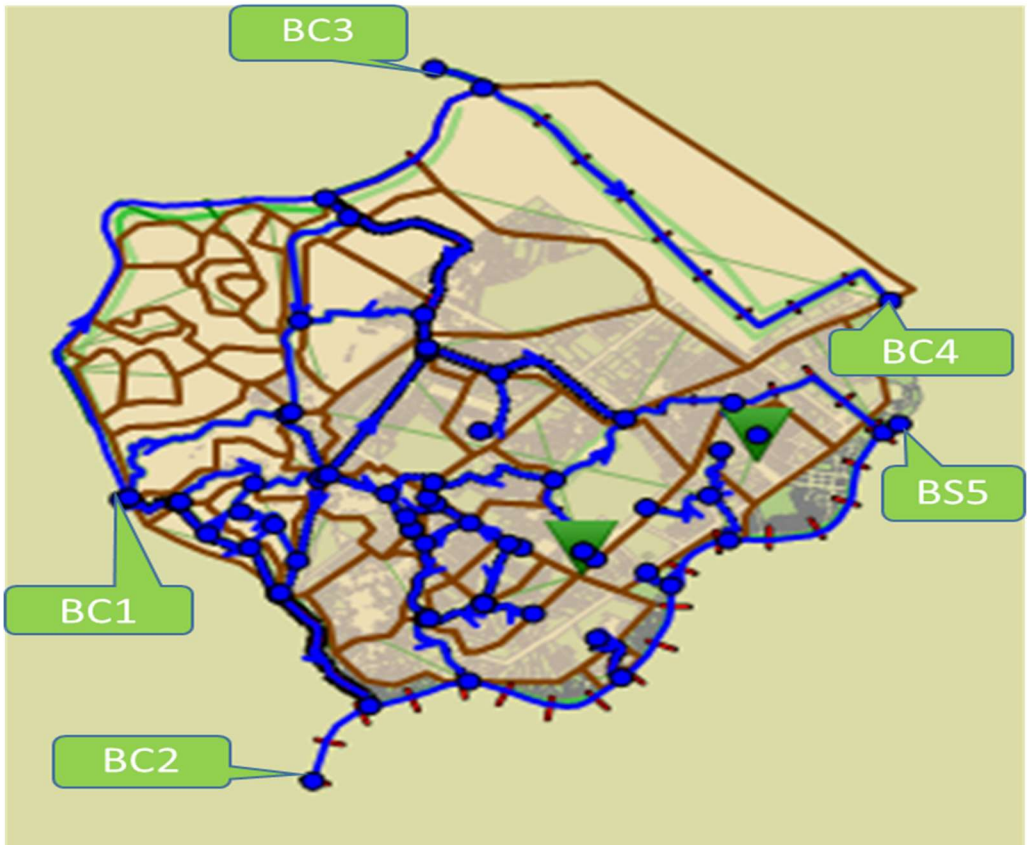

Figure 12. Location of the water level boundaries for the core city model

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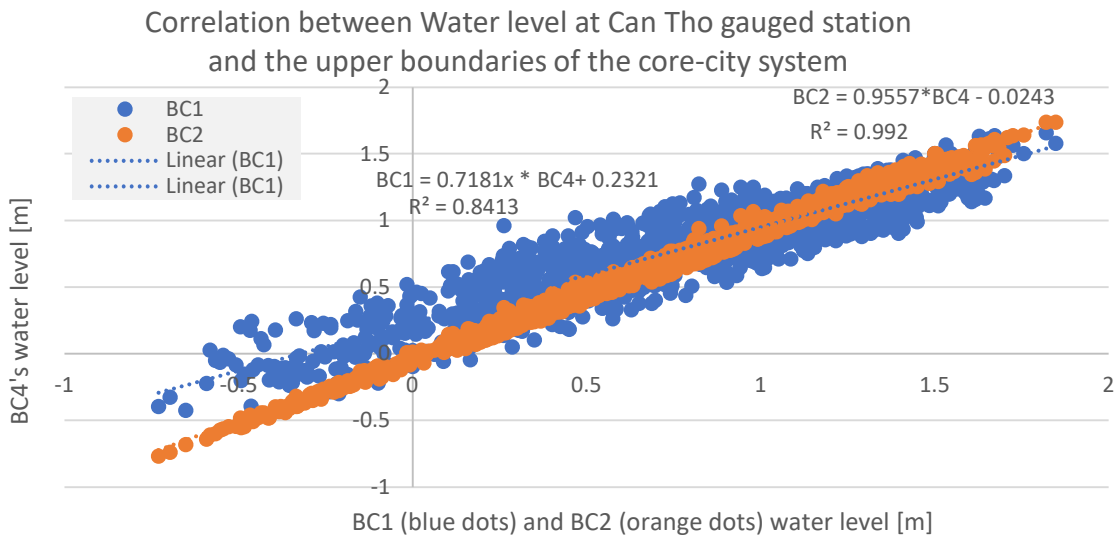

Figure 13. Correlation between the water level at Can Tho station (Hau River) and upper boundary

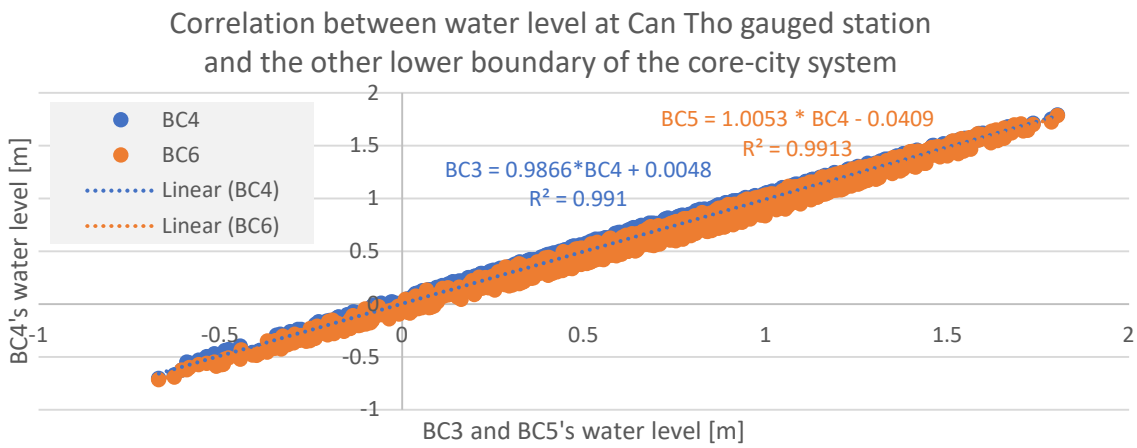

Figure 14. Correlation between water level at Can Tho station (Hau River) and the lower boundary of the core city

A two-dimensional (2D) hydraulic model was established for the core urban area of Can Tho City to simulate detailed overland flow and flood inundation in the urban environment. This model was developed using the MIKE+ modeling platform (developed by DHI). This model simulates the urban drainage system, canal network, and detailed topography of the core area. The setup was based on available GIS data layers, including elevation, land use, and drainage infrastructure. The MIKE+ software was selected for its capability to integrate surface runoff and pipe flow processes in urban flood modeling, ensuring reliable representation of hydrodynamic interactions between rainfall, surface flow, and the drainage network. The core urban area is approximately 2400 hectares, but due to the boundary condition requirements of the hydraulic model, the model domain was extended to include surrounding areas (Figure 11), encompassing the Binh Thuy River to the north; the Cai Son canal and the Muong Khai ditch to the west, the Khai Luong River to the east, and the Can Tho River to the south. This expanded domain allows the model to capture the full range of floodwater sources and flow directions.

Typically, flow originates from the Binh Thuy River and the Can Tho River, discharging into the Hau River. However, due to the influence of East Sea tides, the water level in the Hau River at Can Tho and in the canal system fluctuates with the tide, even during upstream flooding in the Mekong River. Consequently, the boundary conditions for the system must be the water levels of the surrounding rivers, which in this case are the Binh Thuy River, the Can Tho River and the Hau River. These boundary water levels were obtained from the Mekong Delta model results. The correlation with water level data in the Hau River was analyzed. A strong relationship was found between the water level at Can Tho and the boundaries of the core urban area model. This relationship was applied to calculate the boundary water level conditions for the core urban area model to simulate various scenarios. Water levels in the Hau River at the Can Tho station are monitored and forecasted daily, making them available for operational use in the model.

The flood protection wall system of Can Tho was incorporated into this model. In practice, the operation of this system was first tested on November 1, 2023. The inclusion of the flood protection system in the model is crucial for evaluating its effectiveness in mitigating flood risk for the core urban area. The 2D model also integrates other data, such as detailed topography (from LiDAR DEM and 1/5000 scale map), land use maps (to determine surface roughness coefficients), precipitation data (to simulate surface runoff), and data on the drainage system (pipes, manholes, outlets) to provide a comprehensive simulation of urban flooding.

Calibration

Hydraulic model calibration is the process of adjusting model parameters to minimize the difference between simulated results and actual observed data. For the Can Tho core urban area model, reports from WASSCO provided information on the flooded area and water level depths along several inner-city roads. This data is valuable for comparing with the 2D model's simulation results and making necessary adjustments. For instance, if the model indicates significantly different flooding conditions compared to WASSCO's reports for a specific road, parameters such as surface roughness or drainage system characteristics can be adjusted to improve the model's fit with reality.

Water level data from the 2018 flood event on the Hau River were also utilized during the calibration process. Flood bulletin in 2018 recorded afternoon water levels on the Hau River on subsequent days, including the highest water level on October 10, 2018, at 2.23m at 5:30 AM and 2.20m at 6:00 PM. These values provide a critical reference point for evaluating the ability of both the 1D Mekong Delta model and the 2D core urban area model to reproduce the hydrological conditions of a recent major flood event.

Due to the lack of regularly observed hydrological data in the core urban area of Can Tho, the 2D flood model was calibrated and validated using flood statistics provided by the Can Tho Department of Construction for each major flooding event. By comparing the simulated water levels at the Can Tho station with the observed values, model parameters were adjusted to ensure accuracy. The calibration results, presented in Table 3, were found to be acceptable.

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Table 3. Observed and simulated water depth at some flood marks

Inundated road	Observed	Simulated
Mau Than	0.6	0.1 - 0.7
Quang Trung	0.67	0.2 - 0.45
Đường 30/4	0.45	0.2 - 0.45
Trần văn Giàu	0.5	0.2 - 0.5

Validation

After the calibration process, the model requires validation to assess its predictive capability for events not used during calibration. Validation data may include information on other past flood events (e.g., floods or storm surges in years other than 2018) or water level data from other monitoring stations in the area. The objective of validation is to confirm that the model is not only fitted to the calibration dataset but also capable of accurately simulating diverse hydrological conditions.

The validation process typically involves comparing simulated results (e.g., water levels, flood extent, flood depth) with corresponding observed data and evaluating the level of agreement using statistical or visual methods. If the model performs well during validation, it enhances confidence in its ability to be used for simulating future flood scenarios and evaluating the effectiveness of intervention measures.

Table 4. Observed and simulated water depth at some flood marks

Inundated road	Location	Width	Time	Time after rainfall	Observed depth	Model depth
Đường 30/4	Từ M.Thân - T.V.Hoài	4-6m	15-16	30p	0.1	0.1
	Từ VinCom-T.V.Hoài	6-8m	15-16	1	0.25	0.1
	T.V.Hoài - N.V.Linh	4-6m	15h-15h30	30	0.1-0.15	0.1
	N.V.Linh - BV YHCT	6-8m	15-17h	1h30	0.15-0.25	0.1
T.V.Hoài	SN146H1 - Đường 3/2	8-10m	15-17h30	30	0.2-0.3	0.1
T.H.Đạo	H.T.Kháng - M.Thân	6-8m	15h-17h	1	0.15-0.25	0.1 - 0.2
	H.V.Thụ - M.Thân	6-8m	15h-17h	1	0.15-0.26	0.1-0.2
L.T.Trọng	T.H.Đạo - T.B.Trọng	8-10m	15h-16h30	1h30	0.2-0.25	0.1
Đ.Ng.Trãi	T.Phú - T.V.Khéo	6-8m	15-16h	1	0.1-0.2m	0.1
	H.Vương - B.T.Xuân	6-8m	15-16	1	0.1-0.2	0.1
X.V.N.Tĩnh	T.Định - H.V.Thụ	8-10m	15-17	1h30	0.2-0.3	0.1
C.M.T.8	T.Phú - N.V.Cừ	6-8m	15-16	1	0.1-0.2	0.1
N.V.Cừ	M.Thân - CMT8-số lẻ	6-8m	15-16h30	1h30	0.1-0.2	0.1
	M.Thân - CMT8-số chẵn	10-12m	15-17h30	2h30	0.2-0.25	0.1
	ĐS4KDC H.Phát - H.Q.Việt-số chẵn	6-8m	15-16	1	0.1-0.2	0.1-0.1
	ĐS4KDC H.Phát - H.Q.Việt-số lẻ	6-8m	15-16	1	0.1-0.2	0.1-0.2
N.V.Linh	Khu dân cư Metro	6-8m	15-19		0.1-0.2	0.1-0.2

Design scenarios

As this study focuses on risk assessment and operation of tidal-gate systems for urban flood control, the flood scenarios were designed based on extreme but plausible combinations of rainfall and tidal conditions to ensure safety for the protected area. Design rainfall was determined from the intensity–frequency–duration (IFD) curve developed for the Can Tho meteorological station, as shown in Figure 15.

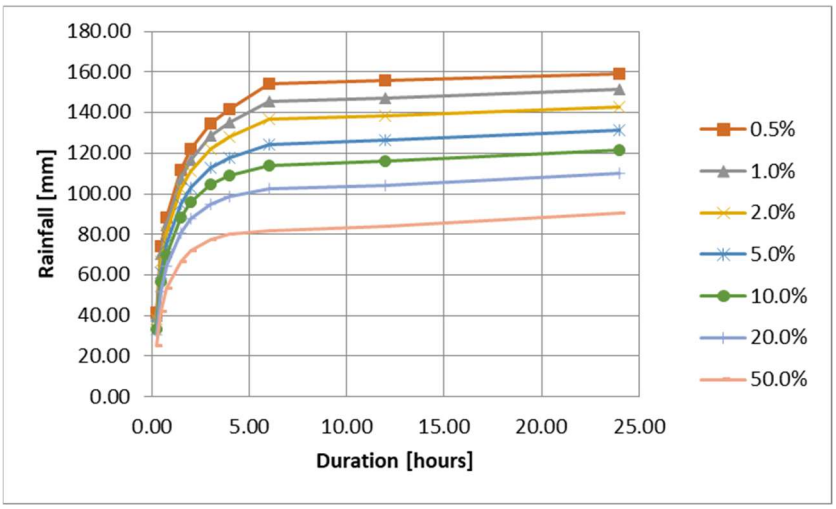


Figure 2. Can Tho - results statistical analysis rainfall (data: 1985 - 2020)

The tidal boundary conditions at the downstream end were defined using the observed water levels at "Muc 93" in An Thach 3 Ward, Vinh Thuan District, Soc Trang Province, following the definition in TCVN 9901:2014. The 2011 tidal series was used as the reference to scale the maximum tidal levels corresponding to the selected recurrence intervals. Table 10 presents the estimated maximum water levels at the Hau River mouth for different return periods, which were used as boundary inputs for the 2D flood model simulations (Table 5).

Table 5. Maximum water levels at the Hau River mouth

	Year	Probability of occurrence					
	2011	**1%**	**2%**	**5%**	**10%**	**20%**	**50%**
Max water level [cm]	234.0	256.7	219.6	183.8	176.8	173.2	171.2

4. RESULTS AND DISCUSSION

After the 2D model for the core urban area was calibrated and validated, various flood scenarios were simulated using the model. These scenarios were developed based on combined conditions of precipitation and tidal water levels, representing events with different recurrence intervals: 5 years (20%), 10 years (10%), 20 years (5%), 50 years (2%), and 100 years (1%).

To develop these scenarios, historical precipitation data from the Can Tho station were statistically analyzed to determine rainfall values corresponding to different return periods.

Similarly, tidal water level data from coastal stations and the Hau River were analyzed to identify extreme tidal levels corresponding to the same return periods. These precipitation and tidal water level conditions were then combined to create input scenarios for the 2D model. For example, the 100-year flood scenario might include a rainfall event with a 100-year recurrence interval combined with the highest tidal water level with a 100-year recurrence interval. However, it is also important to consider other combinations that could lead to severe flooding, such as a less extreme rainfall event coinciding with an exceptionally high tide.

When these scenarios were run on the 2D model, the output data included information on floodwater levels and inundation extents at various locations within the core urban area. This data was subsequently used to generate flood status maps for each scenario. These maps typically display flood depths using different color gradients, allowing for easy identification of the most severely affected areas and the level of inundation in each zone (See Figure 16).

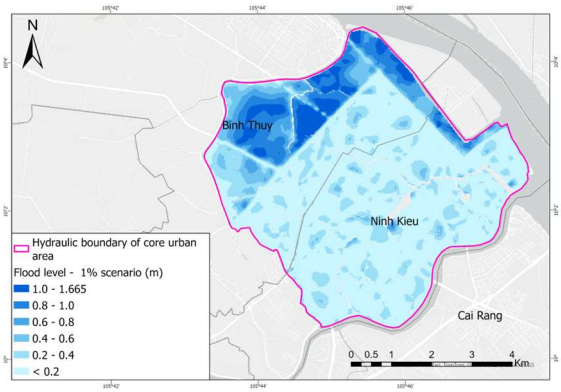
The maps show the distribution of flood in the core city area. In the North-West, a large area is not protected by the tide wall system. Therefore, this part has a higher flood level than the area inside the tide-wall. The water level increased from 0.6m in the 5 years scenario to more than 1m or reached 1.6m in the 100 years scenario.

A key finding of this study is the spatial distribution of flood risk with the new tide wall system in operation. The maps in Figure 16 clearly show that the area inside the tide wall experience significantly reduced inundation, primarily shallow flooding (<0.4 m) even in a 100-year scenario. However, the model reveals a critical trade-off: areas outside the protective embankment, such as the large residential zone in the North-West, now face concentrated and deeper flooding. For example, in the 100-year scenario (Figure 6a), this unprotected area experiences inundation depths exceeding 1.0 m, which is significantly higher than pre-embankment flood levels might have been. This suggests the tide wall, while protecting the central core, may inadvertently increase the hydraulic load and subsequent flood severity in adjacent, unprotected zones.

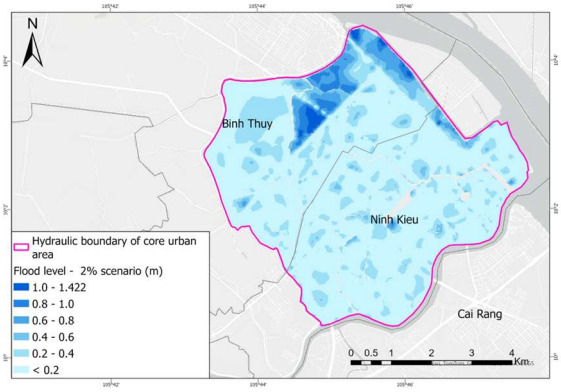
From the flood data, the area of flood has been calculated in GIS and presented in the following Table 6 and chart in Figure 17.

Table 6. Area of flood occupation by ha

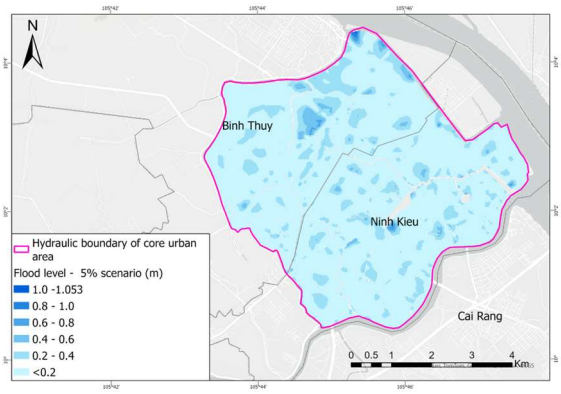
	Area of flood occupation (ha)				
Depth (m)	**Scenario 1%**	**Scenario 2%**	**Scenario 5%**	**Scenario 10%**	**Scenario 20%**
<0.2 m	2024.72	2397.12	2791	2960.72	3064.16
0.2 - 0.4 m	572.32	629.4	531.56	398.84	316.6
0.4 - 0.6 m	218.72	145.96	67.48	39.28	18.4
0.6 - 0.8 m	173.04	131.56	9.48	2.56	2.28
0.8 - 1.0 m	247.04	72.4	1.68	0.04	0
>1 m	165.6	25	0.24	0	0



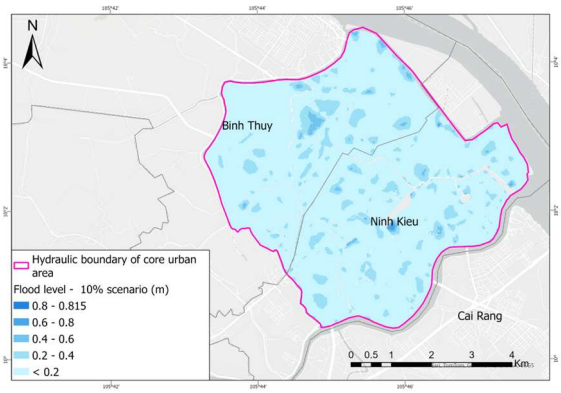
(a) Flood inundation map according to 1% scenario at a 100-year return period



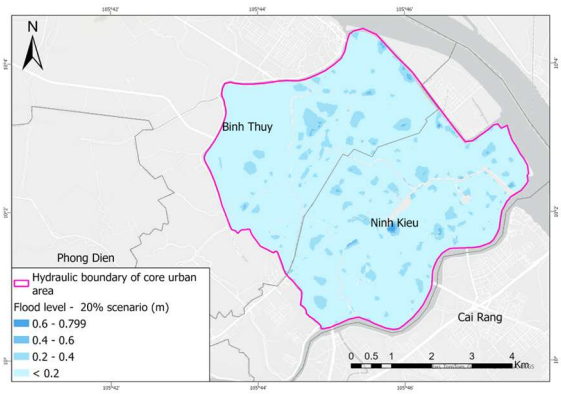
(b) Flood inundation map according to 2% scenario at a 50-year return period



(c) Flood inundation map according to 5% scenario at a 20-year return period



(d) Flood inundation map according to 10% scenario at a 10-year return period



(e) Flood inundation map according to 20% scenario at a 5-year return period

Figure 16. Flood inundation maps based on the scenarios

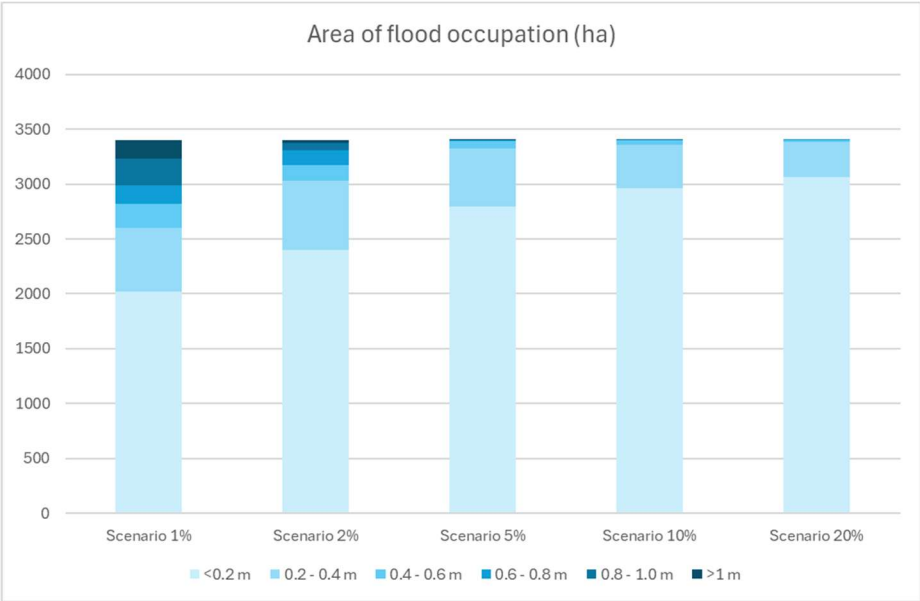


Figure 17. Area of flood occupation

The analysis of simulation results reveals a critical, non-linear escalation in flood hazard corresponding to event severity. While frequent events (e.g., 5-year return period) are characterized by widespread but predominantly shallow flooding (<0.4 m), the area experiencing deep and dangerous inundation (>0.6 m) expands dramatically in rarer events. This high-risk zone grows from a negligible 2.28 ha in the 5-year scenario to over 585 ha in the 100-year scenario—a more than 250-fold increase. This finding demonstrates that the primary threat from extreme flood events is the sharp increase in inundation depth and severity, not merely a gradual expansion of the total flooded area.

To further contextualize our findings, we compared the simulated flood patterns to historical observations beyond the 2018 calibration event. For instance, major flooding was reported in October 2019 and October 2022, with news articles and municipal reports describing significant inundation along major roads like Mau Than and Tran Hung Dao. Our 20-year return period simulation (Figure 16c), which shows flood depths between 0.4 m and 0.6 m in these specific locations, aligns well with these qualitative historical accounts. This consistency lends further confidence to the model's ability to represent real-world flood dynamics in Can Tho.

5. CONCLUSION AND RECOMMENDATIONS

This study has presented the development and application of an integrated 1D-2D hydraulic model for assessing the flood status in the core urban area of Can Tho City. The utilization of detailed topographic data from LiDAR, combined with data on precipitation, the drainage system, and the river network, has enabled the construction of a model capable of simulating the complex hydraulic processes within the study area with reasonable accuracy. The

calibration and validation of the model using historical data, including the 2018 flood event and reports from WASSCO, have enhanced the model's reliability

The simulation of various flood scenarios for return periods of 5, 10, 20, 50, and 100 years has provided critical insights into the flood risk within the core urban area of Can Tho City. The resulting flood status maps are valuable tools for urban managers, planners, and relevant authorities in making informed decisions related to flood risk management.

Based on the findings of this research, several recommendations can be made to enhance flood resilience in Can Tho City. Firstly, consideration should be given to updating the topographic data, particularly the LiDAR data, to reflect potential changes in the urban area since 2011 due to development and construction. Secondly, continued collection and analysis of data on the performance of the urban drainage system are necessary, including information on blockage, design capacity and responsiveness to heavy rainfall events. Thirdly, further research into the interaction between rainfall-induced flooding and tidal flooding is warranted to develop more comprehensive flood scenarios. Finally, the development of a real-time flood forecasting system based on the developed hydraulic model could provide early warning information to residents and authorities, helping to mitigate the impacts of flood events.

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