

ASSESSMENT OF THE CURRENT STATUS AND CHALLENGES OF THE IRRIGATION SYSTEM IN SUBREGION X - SOUTHERN CAMAU FOR AQUACULTURE DEVELOPMENT

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Abstract

The Southern Ca Mau Sub-region X, which is one of the 18 key irrigation sub-regions, has been equipped with a closed sluice system to support aquaculture development. The main objective of this study is to analyze and evaluate the current status and challenges in the management and operation of the sub-region's irrigation system, aiming for an objective view of the existing problems. Despite significant investment, the system at the time of the study was still operating primarily based on experience, lacking standardized operating procedures. This has resulted in a failure to fully optimize the production potential for the local people. To address this issue, the study adopted a dual approach: a SWOT analysis was conducted to assess internal and external factors, combined with the use of the MIKE 11 hydrodynamic model to simulate alternative operational scenarios. The analysis results pointed out management weaknesses, particularly the lack of consistency in operation. The MIKE 11 simulation results indicated that Scenario KB5—controlling a main sluice cluster (PT3) along with the Bao Chau sluice—is the optimal strategy. This strategy achieves water level reduction efficiency comparable to broader control scenarios but is more economically effective and operationally feasible for years with average or low water levels. This research provides an important basis for developing adaptive operating procedures to

ensure long-term sustainability for aquaculture development in the sub-region.

Keywords: Aquaculture, Subregion X of south Ca Mau, MIKE11, SWOT.

1. Introduction

Ca Mau, the southernmost province of Vietnam, is characterized by complex geographical and hydrological settings. With three sides bordered by the sea, it forms a peninsula subject to two distinct tidal regimes: The diurnal tide from the western coast and the irregular semi-diurnal tide from the eastern coast. Historically, Irrigation Systems (IS) in the province were designed primarily for rice cultivation. However, since 2001, Ca Mau has implemented a large-scale transformation from low-yield rice farming to shrimp aquaculture, a transition widely supported by local communities. To support this shift, the province divided the entire production area into 18 sub-regions, covering approximately 314,000 hectares (Figure 1). To date, investment plans for 16 sub-regions have been approved, and construction is ongoing in Sub-regions II, III, V, VII, X, XVII, XVIII, as well as the Tan Duyet hydraulic sector in Tan Duyet area.

The objectives of these irrigation projects extend beyond agricultural production. They are intended to mitigate tidal inundation, ensure reliable freshwater supply for aquaculture, limit sedimentation in canals, and maintain hydraulic circulation. At the same time, they enhance disease control, facilitate both inland waterway and road transport, and create a foundation for rural development. Collectively, these measures contribute to disaster risk reduction, environmental protection, climate change adaptation, and livelihood

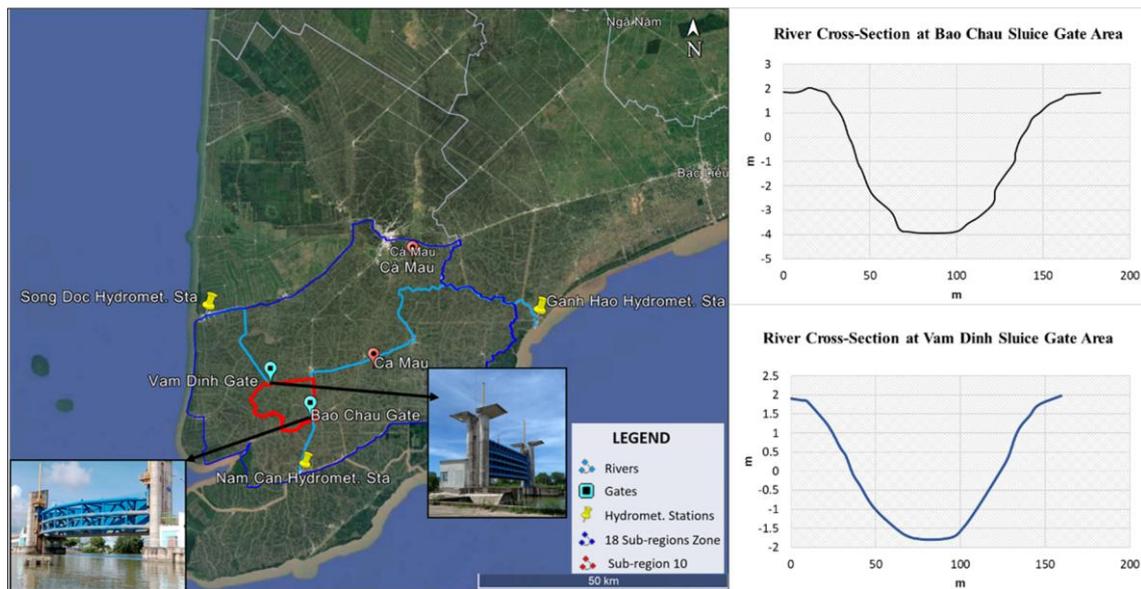


Figure 1. Location of water level surveys, river cross-sections at Vam Dinh and Bao Chau sluice gates, and meteorological and hydrological stations

improvement [1]. Within this context, the system investigated in this study is located in Sub-region X - Southern Ca Mau, encompassing Tan Hung Tay, Viet Thang, Tran Thoi communes and Cai Nuoc area, all under Ca Mau Province. The sub-region is bounded by the Cai Nuoc - Vam Dinh road canal to the north, National Highway 1A to the east, the Bay Hap River to the south, and the Mang Ro canal to the west [Figure 7].

The closed irrigation works of Sub-region X are part of the Mekong Delta Rural Water Resources Management Project [2]. Despite considerable investment, most sluices, dikes, and canals are still operated empirically rather than under standardized and authorized procedures. Since construction, many sluices have functioned in a free-flow state, which has prevented the system from realizing its intended functions. As a result, flooding persists during high tides, particularly when combined with heavy rainfall. These events disrupt rural livelihoods, damage transport infrastructure, and frequently cause overtopping of aquaculture embankments, leading to significant production losses. Issues such as waterlogging, sedimentation, and environmental degradation are becoming more severe and are projected to intensify in the future. Thus, establishing effective operational protocols is critical not only for disaster prevention and environmental protection but also for the long-term sustainability of aquaculture in the sub-region.

At present, the sluice system in Sub-region X - Southern Ca Mau lacks a standardized operational protocol and a defined schedule for individual sluice clusters. Instead, gate operations are conducted on an ad hoc basis, primarily responding to the specific water management requirements of different production areas within the irrigation network. In practice, the opening and closing of sluices are implemented based on requests from the District Departments of Agriculture and Rural Development of Phu Tan and Cai Nuoc. The existing operational regime is largely empirical, relying on observed water levels rather than formalized criteria. Specifically, when the downstream water level at the Bao Chau sluice reaches 1.25m, the gate is closed to prevent tidal intrusion, while other sluices remain in free-flow operation. Consequently, it is necessary to conduct a comparative assessment between the fully controlled operation scenarios and the baseline condition to evaluate the relative effectiveness and potential benefits of different management strategies.

Moreover, the combined effects of climate change, sea-level rise, and unsystematic shifts in aquaculture practices have imposed additional pressures, making system operation increasingly complex and demanding. Addressing these challenges requires a rigorous assessment of current conditions, operational constraints, and potential management options. Accordingly, this study employs a dual approach: first, a SWOT analysis is applied to evaluate the strengths,

weaknesses, opportunities, and threats of the existing system, thereby providing an objective assessment of its performance and limitations; second, the MIKE 11 hydrodynamic model is integrated to simulate system operations under alternative scenarios, enabling comparative evaluation against baseline conditions.

2. Research Methodology

This study aims to simulate baseline water levels and scenario-based variations within the irrigation system of Sub-region X - Southern Ca Mau. Over recent decades, a wide range of mathematical models has been developed for water resources planning, management, and disaster risk reduction, including VRSAP, SOBEK, and MIKE. In this research, the MIKE 11 model - an integral component of the MIKE modeling suite - was adopted. MIKE 11 is specifically designed for simulating river flows and their interaction with floodplains. Compared with alternative modeling tools, MIKE 11 offers several key advantages: (i) seamless integration with GIS; (ii) strong connectivity with other modules of the MIKE system, such as the NAM rainfall-runoff model, the two-dimensional hydrodynamic model MIKE 21, and the integrated surface water-groundwater-evapotranspiration model MIKE SHE; (iii) the capability to simulate water quality and solute transport; and (iv) flexibility in modeling hydraulic structure operations.

MIKE 11, developed by the Danish Hydraulic Institute, is a one-dimensional hydrodynamic model widely applied for river and canal flow simulations [3]. Its hydrodynamic module constitutes the computational core, solving the one-dimensional Saint-Venant equations for continuity and momentum conservation using the six-point implicit finite-difference Q-H scheme proposed by Abbott and Ionescu [4]. This modeling framework provides a robust basis for analyzing water-level dynamics and assessing the effectiveness of operational strategies under both present and projected future conditions.

Over the past decades, MIKE 11 has been widely applied in irrigation and water resources management. Previous studies have demonstrated its effectiveness in simulating sluice gate operations, reservoir regulation, and salinity intrusion control in the Mekong Delta [5, 6, 7, 8]. More recent applications include evaluating sustainable adaptation strategies, improving water quality management in aquaculture and predicting future salinity dynamics under climate change scenarios [9, 10, 11]. These applications

highlight the flexibility and reliability of MIKE 11, providing a strong foundation for its application to the Sub-region X system in Ca Mau.

2.1. Data and Model setup

Data Collection

The datasets employed in this study were compiled from a combination of field surveys and secondary sources, including the Ca Mau Provincial Center for Irrigation Works Management and Exploitation, the Department of Agriculture and Rural Development (DARD) of Phu Tan area, and the DARD of Cai Nuoc area.

- Hydrological data and cross-sections: Water level measurements and surveyed river cross-sections at Vam Dinh and Bao Chau sluices for 2021 and 2022 (Figure 1), together with hydrological boundary data for model construction (Figures 2 and 3).

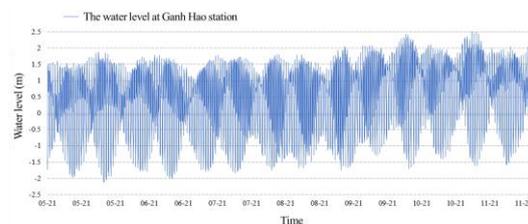


Figure 2. The water level at Ganh Hao station in 2021 (representing the East Sea tide)

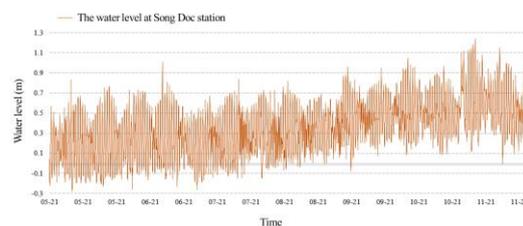


Figure 3. The water level at Song Doc station in 2021 (representing the West Sea tide)

- Rainfall data: Daily rainfall in 2021 from Ganh Hao, Nam Can, and Song Doc stations (Figure 4).

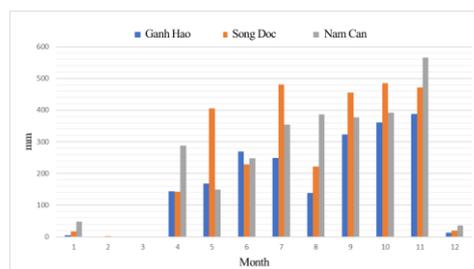


Figure 4. Rainfall at Ganh Hao, Nam Can and Song Doc stations

- Agricultural and aquaculture data: Production plans, farming models, cultivated and aquaculture areas, and seasonal calendars from 2018-2021.

- Operational status of sluices: Information obtained from official documents, field surveys, and stakeholder interviews, subsequently integrated into the SWOT analysis.

Rainfall analysis indicates that annual precipitation at Ganh Hao station (2057.3mm) was substantially lower than at Song Doc (2928mm) and Nam Can (2845.1mm). The rainy season extends from May to November, accounting for approximately 99% of annual rainfall.

Model setup

The MIKE 11 modeling system consists of several editors:

- Network Editor: River and canal network configuration;
- Cross-Section Editor: River cross-section data;
- Boundary Editor: Specification of boundary conditions;
- Time Series Files: Hydrological input series;
- HD Parameter File: Hydraulic parameters.

Each component can be independently configured and modified. All information is subsequently consolidated within the MIKE 11 Simulation Editor to execute model runs. The overall structure of the MIKE 11 setup is shown in Figure 5.

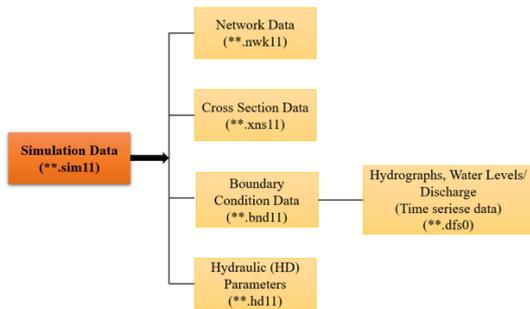


Figure 5. The overall structure of the MIKE 11 model

Given the dense river-canal network of the study area, the modeling focused on the primary rivers and canals that exert the greatest influence on system hydraulics (Figure 6). The hydraulic scheme comprises 101 main river branches, 25 hydraulic structures, 7386 nodes, and 400 surveyed cross-sections.

Water level boundaries were assigned at six locations: Three on major rivers (Nam Can station on the Cua Lon river, Ganh Hao station at the Ganh Hao

river mouth, and Song Doc station at the Ong Doc river mouth) and three on smaller canal boundaries. The numerical model was developed to solve hydrodynamic equations through a sequence of numerical analyses, providing hydrodynamic simulations for the study area and forecasting conditions for different future periods. It can also be employed to reconstruct or predict missing data intervals. The model was implemented for the years 2021 and 2022 in the study domain. Model calibration was performed by comparing simulated outputs with representative observed data collected in July 2021 at the Vam Dinh and Bao Chau sluice gates. The calibration process was completed once the model performance reached acceptable thresholds, evaluated using the Nash-Sutcliffe Efficiency (NSE) and the Root Mean Squared Error (RMSE). The NSE assesses the degree of agreement between simulated and observed data, with values approaching 1 indicating higher model accuracy. The RMSE evaluates model performance by quantifying the deviation between simulated and observed data, where lower RMSE values indicate higher reliability [12]. Subsequently, model validation was carried out using data from July 2022 at the same sluice gates to ensure temporal and spatial consistency between the calibration and validation phases.

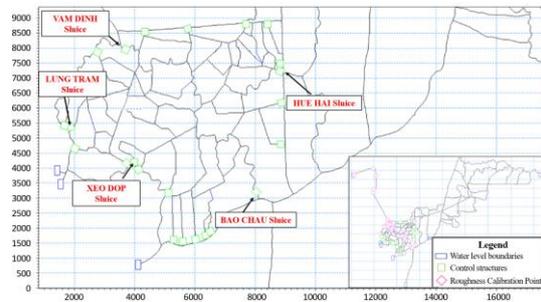


Figure 6. The river and canal network of the X-Southern Ca Mau sub-region in the MIKE 11 model

Table 1. Model calibration and Validation results [12]

Calibration Results				
No.	Sluice	NSE	RMSE	Evaluation
1	Vam Dinh	0,90	0,03	Excellent
2	Bao Chau	0,93	0,08	Excellent
Validation Results				
No.	Sluice	NSE	RMSE	Evaluation
1	Vam Dinh	0,83	0,05	Excellent
2	Bao Chau	0,82	0,2	Excellent

The irrigation system model for Subregion X-southern Ca Mau had previously been calibrated and

validated in the study Application of the MIKE11 Model in Irrigation System Operation: A Case Study of Subregion X - southern Ca Mau [13]. Calibration and validation outcomes are summarized in Table 1. Building on this foundation, the present study extends the model application to simulate water levels under multiple operational scenarios. By comparing water level dynamics across different management options, both within the canal network and at sluice gates before and after regulation, this analysis generates insights into rational and adaptive operating strategies.

2.2. SWOT Analysis Framework

In addition to hydrodynamic modeling, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to assess the operational efficiency and management capacity of the Sub-region X irrigation system. This analytical framework provides a structured methodology for identifying both internal and external factors that influence system performance and long-term sustainability [14, 15].

The strengths and weaknesses relate to internal conditions such as existing infrastructure, operational practices, and institutional management capacity, whereas the opportunities and threats encompass external drivers including climatic variability, market dynamics, policy environments, and socio-economic trends.

The analysis integrated multiple sources of information, combining field observations, stakeholder interviews with local farmers, irrigation operators, and representatives from the District Departments of Agriculture and Rural Development, along with secondary data obtained from official reports and project documentation. Furthermore, hydrodynamic simulation outputs from the MIKE 11 model were incorporated to quantitatively support the assessment.

This integrated approach enabled both qualitative and quantitative evaluation of system performance, offering a comprehensive understanding of the management context, operational constraints, and strategic options for enhancing the sustainability of the Sub-region X irrigation network.

3. Results and Discussion

3.1. Simulation Results and Evaluation of the Irrigation System

Current Status of the Irrigation System

Based on a comprehensive compilation of secondary data, field surveys, and structured interviews with managers and operators regarding the

condition and operation of hydraulic works for flood tide control in Sub-region X - Southern Ca Mau, the following assessment of the current irrigation system was conducted.

River-Canal Conditions and Irrigation System Quality in the Study Area.

River and canal conditions

The river network in the study area is strongly influenced by both the East Sea and West Sea tidal regimes, resulting in highly complex hydrodynamic conditions. The East Sea tide predominates, entering the project area via the Bo De estuary through the Cai Lon river and the Cai Nhap canal into the southeastern zone. Conversely, the West Sea tide penetrates through the Bay Hap and Cai Doi Vam estuaries, impacting the northwestern portion of the project area.

The project basin is bounded by major rivers, including the Bay Hap, Bao Chau, and Mang Ro rivers, which provide sufficient water supply for intake and drainage within the project area. Key cross-sectional dimensions are as follows:

- Bay Hap river: Width 80-100 m; bed elevation - 3.5m to -4.0m.

- Bao Chau - Dong Cung river: width 40-50 m; bed elevation -3.0m to -3.5m, deepening toward the Bay Hap estuary.

- Mang Ro River: width 50-60 m; bed elevation -3.0m to -3.5m.

The canal network is dense but predominantly shallow, with cross-sectional widths ranging from 8 to 30 m and bed elevations between -1.0m and -1.5m. Many canals are severely affected by bank erosion due to intensive waterway traffic. Some primary canals (Dan Quan and Ca Nay) have experienced significant siltation, hindering navigation for dredging barges and excavators. Spatial distribution of rivers and canals is illustrated in Figure 7.

Quality of the irrigation system

Within the sub-region, 25 sluice gates have been constructed, and soft barriers reinforced with mangrove vegetation protect 8,175m of embankments along the Mang Ro - Phu Thuan segment. In addition, the system comprises approximately 859 small sluices along tertiary canals and field channels. Five main dikes are included in the system:

1. Mang Ro - Lo Xe dike;
2. Mang Ro - Phu Thuan dike;
3. Cai Nuoc - Vam Dinh road embankment;

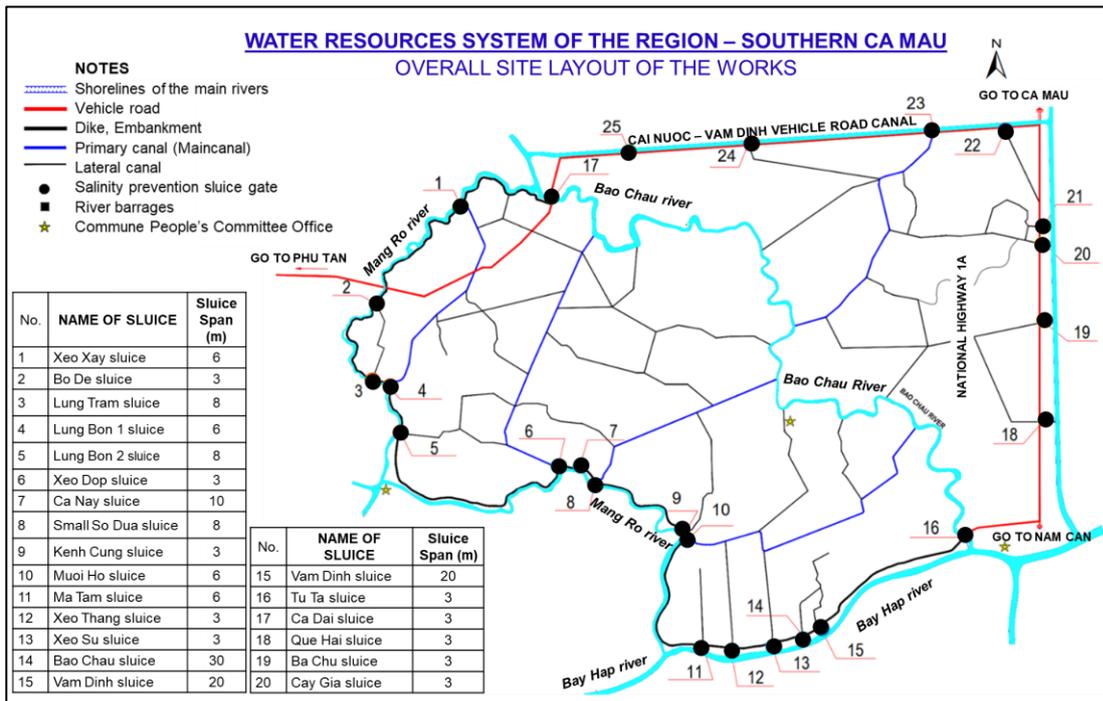


Figure 7. Map of the Hydraulic Infrastructure System in Sub-region X, Southern Ca Mau

- Western Bao Chau - Dam Cung dike;
- Eastern Bao Chau - Dam Cung dike.

The total length of these dikes is 67.73km. Together with secondary embankments, they create enclosed production compartments that enhance flood management and irrigation efficiency.

Survey results indicate that 63.3% of managers and operators rated the overall condition of hydraulic works as moderate, while 30% rated it as high. Regarding local government attention and investment, 43.3% of respondents considered it high, and none rated it low. These findings, presented in Figure 8, underscore the increasing importance of infrastructure investment for the irrigation system.

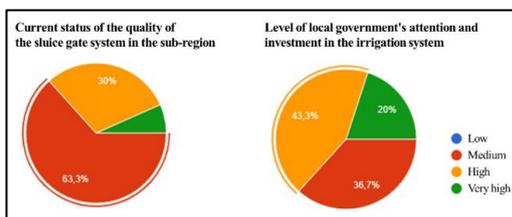


Figure 8. Results of manager consultation

Aquaculture Production in the Study Area

From 2018 to 2021, the aquaculture area remained stable, reaching 7,276.09ha in 2021, predominantly distributed across three communes: Viet Thang

(3,525.72ha; 48.46%), Tran Thoi (1,626.90ha; 22.36%), and Tan Hung Tay (1,517.59 ha; 20.86%).

During the same period, aquaculture and capture production exhibited an increasing trend, reaching 10,519.01 tons in 2021. Shrimp production was distributed as follows: Viet Thang (5,711.86 tons), Tan Hung Tay (2,458.58 tons), Tran Thoi (1,560.60 tons), Phu Thuan (506.65 tons), and Cai Nuoc town (281.02 tons).

Table 2. Aquaculture Area and Shrimp Production in the Project Region, 2021 [16, 17]

Commune/ Town	Aquaculture Area (ha)	Shrimp Production (capture and farming, tons)
Tan Hung Tay	1.517,59	2.458,58
Viet Thang	3.525,72	5.711,86
Phu Thuan	312,92	506,95
Tran Thoi	1.626,90	1.560,60
Cai Nuoc	292,96	281,02
Total	5.758,50	8.060,43

Operational Capacity and Current Performance

Sluice operations in Sub-region X during the late months of the year generally met the requirements for flood tide control and local production. In canals with

minimal siltation and significant water level differentials, sluices equipped with automatic gates performed relatively effectively.

Water level measurement data:

However, field observations revealed that numerous automatic sluices experience weak flow conditions and substantial silt deposition at the inlets, resulting in operational delays. Of the 25 sluices, 22 are equipped with automatic bi-directional steel gates, which substantially influence operational efficiency and necessitate timely corrective measures. The remaining three sluices - Vam Dinh, Bao Chau, and So Dua Lon - utilize flat steel gates operated hydraulically (Figure 9).

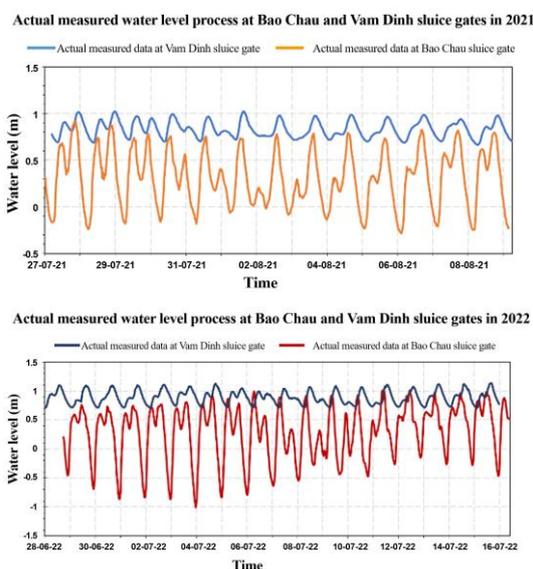


Figure 9. Actual water level measured at the Vam Dinh and Bao Chau sluice gates in 2021 (model calibration) and 2022 (model validation)

3.2. SWOT Analysis of Agricultural Production in Sub-region X - Southern Ca Mau

Strengths:

The study area, situated in Ca Mau province - one of the four strategic provinces within the Mekong Delta's economic development zone—possesses multiple advantages derived from fertile soils and abundant forest and marine resources. These factors provide substantial potential for the development of aquaculture, integrated agriculture-forestry systems, seafood processing industries, export-oriented production, service sectors, tourism, and oil and gas exploitation.

Furthermore, to proactively adapt to climate

change and enhance productivity, product quality, added value, and competitiveness for both domestic and international markets, the province has recently established numerous value-chain production linkages. Consequently, several certified shrimp farming zones have been developed under standards such as VietGAP, ASC, B.A.P., and Selva Shrimp, facilitating market access to supermarkets and high-end restaurants in demanding markets, including the United States, Japan, and the European Union. Ca Mau shrimp is now exported to over 90 countries and territories worldwide.

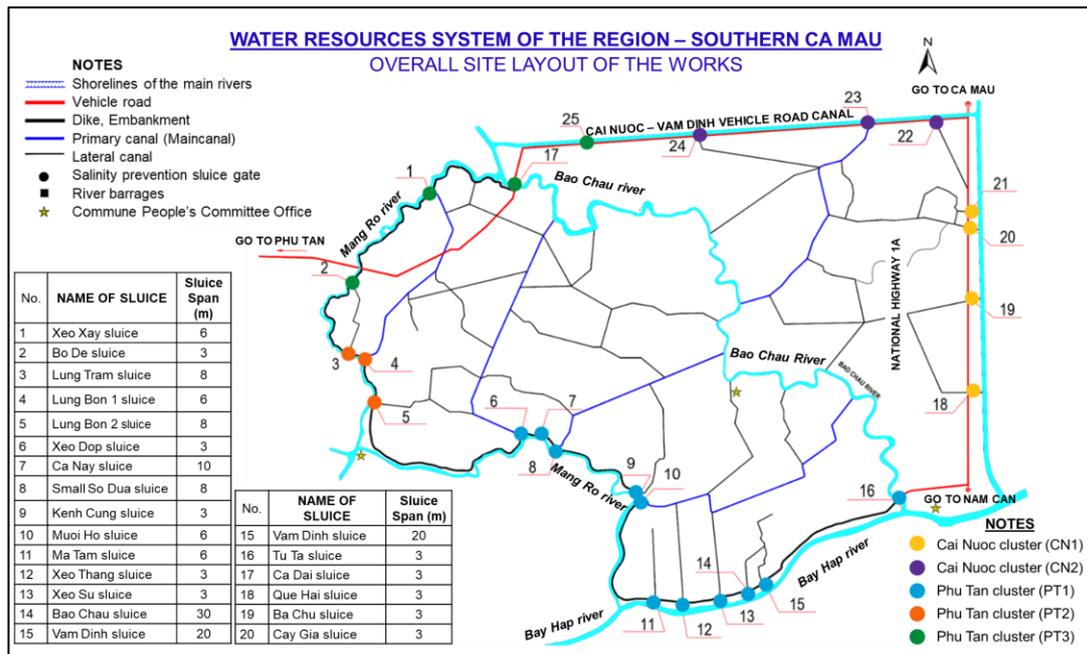
Additionally, the value of shrimp production has continued to increase, while the technical proficiency of local farmers has significantly improved compared to previous years. In Sub-region X, the Phu Tan area (Ca Mau Province) recently restructured-has received considerable investment in road infrastructure. In recent years, rural transport networks have been expanded, connecting communes via road; however, waterway transport remains the dominant mode, with trunk canals linking neighboring area and an interconnected system of primary, secondary, tertiary, and field canals forming an extensive waterway network.

Weaknesses:

Despite the enclosure of the irrigation system and the installation of sluices for water level regulation, the absence of unified and standardized operational procedures has impeded the transition to modern production models. As a result, agricultural production remains unstable, highly weather-dependent, and lacking in autonomy. Coastal zones and estuarine areas continue to experience saline intrusion, while inland areas frequently suffer from flooding during the rainy season, leading to suboptimal agricultural outcomes.

The region is subject to two tidal regimes (East and West Seas), generating complex hydrodynamics in rivers and canals. These conditions create “confluence zones” along major rivers and within inland areas, complicating water supply and drainage. Such zones frequently accumulate waste and pollutants, posing significant environmental risks.

Shrimp farming practices remain predominantly traditional, with farmers often failing to adhere strictly to scientific protocols or contractual obligations with companies. Farmers are not yet organized into cooperatives or associations, resulting in inconsistent product quality and output, reduced competitiveness, and limited access to government or external support



Source: Ca Mau Center for Irrigation Works Management and Operation, 2023

Figure 10. Map of Operational Clusters of Hydraulic Structures in Sub-region X – Southern Ca Mau

Table 3. Detailed Operation Scenarios of Sluice Clusters during the Rainy season

No.	Scenario	PT1 Cluster	PT2 Cluster	PT3 Cluster	CN1 Cluster	CN2 Cluster
1	KBN	M2C	M2C	M2C	M2C	M2C
2	KSTB	KS	KS	KS	KS	KS
3	KB1	KS (Bao Chau sluice VHKS)	M2C	M2C (Vam Dinh sluice VHKS)	M2C	M2C
4	KB2	KS-B (Bao Chau sluice VHKS)	M2C	M2C (Vam Dinh sluice VHKS)	KS-B	M2C
5	KB3	KS-B (Bao Chau sluice VHKS)	KS-B	M2C (Vam Dinh sluice VHKS)	KS-B	M2C
6	KB4	KS-B (Bao Chau sluice VHKS)	KS-B	KS-B (Vam Dinh sluice VHKS)	M2C	M2C
7	KB5	M2C (Bao Chau sluice VHKS)	M2C	KS-B (Vam Dinh sluice VHKS)	M2C	M2C

programs. Consequently, shrimp products often fail to meet certifications such as VietGAP, ASC, EU Organic, or other international standards, restricting access to global export markets.

Opportunities:

Currently, Phu Tan area has restructured its production system, reducing the proportion of agriculture and forestry while expanding aquaculture, particularly shrimp farming. This transition has substantially increased the economic value per unit of land. Similarly, Cai Nuoc area has shifted from monoculture shrimp farming to integrated systems combining shrimp with other high-value aquatic species, yielding promising preliminary results.

Ca Mau’s eco-shrimp brand has achieved strong international recognition. According to the provincial

shrimp development plan, all forest-shrimp farming areas will soon be certified under international standards, facilitating expansion of certified shrimp-forest farming zones. The World Bank is currently supporting an eco-shrimp development project in Ca Mau, and the province is actively negotiating partnerships and intensifying training programs to enhance environmental protection practices, support reforestation for adequate coverage, and invest in irrigation and infrastructure to meet the standards of certified aquaculture zones.

Threats:

Despite its significant potential, Ca Mau’s shrimp industry has not yet reached full development and continues to face numerous challenges, including climate change impacts, underdeveloped

infrastructure, frequent disease outbreaks, soil degradation, fragmented small-scale production without cooperative linkages, unstable markets, and limited technological adoption. Export activities encounter additional barriers, such as rising technical, trade, and food safety standards, stricter traceability requirements, and increasing competition from other

shrimp-exporting countries.

3.3. Simulation of Current Conditions and Operational Scenarios

To ensure an adequate water supply for agricultural production in the area during sluice gate operations, two key factors must be considered. First, overtopping should be prevented, as the average

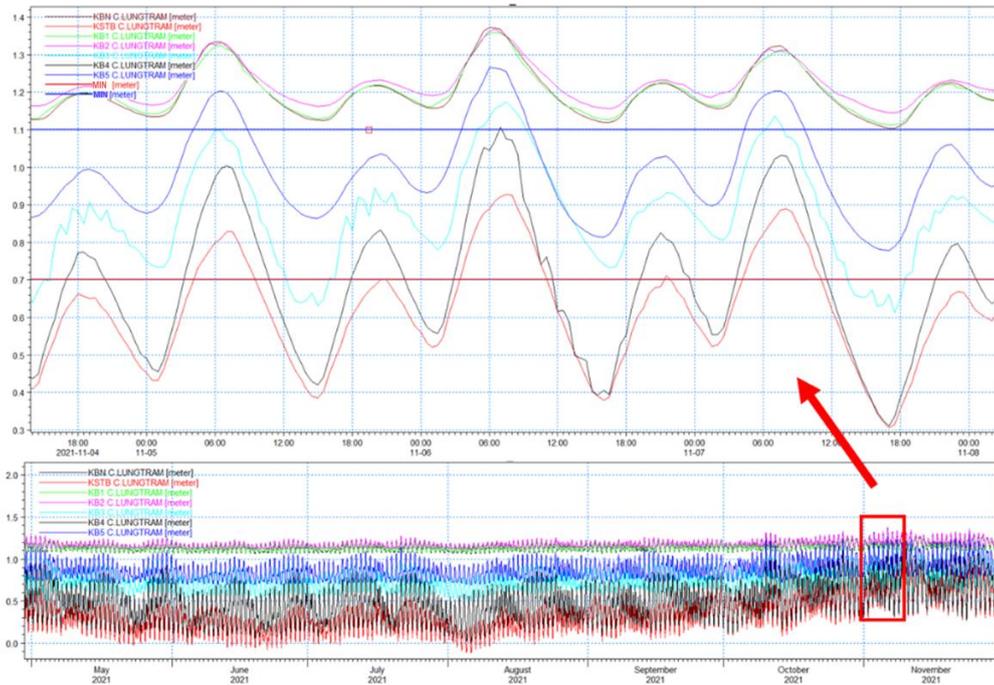


Figure 11. Simulated water level results at Lung Tram sluice gate

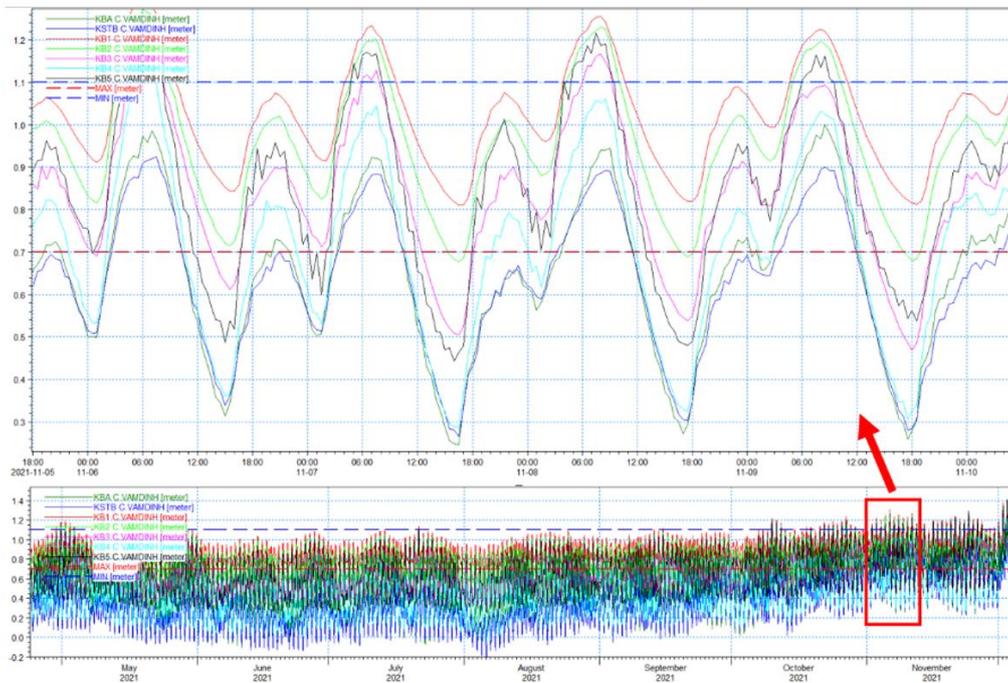


Figure 11. Simulated water level results at Lung Tram sluice gate

embankment elevation ranges from 1.15 to 1.25m. Second, since the natural field surface elevation varies between 0.25 and 0.40m, the water level within the production fields must be maintained approximately 0.4-0.6m above the natural ground surface. Accordingly, water levels ranging from 0.7 to 1.1m were selected as the basis for evaluating the operational efficiency of the different management scenarios

For management purposes, hydraulic structures in the study area were classified into five operational clusters, each exhibiting similar functional characteristics (Figure 10). Water level variations in canals under different management scenarios were simulated and compared with baseline conditions,

with detailed scenarios presented in Table 3. In this context, KB1, KB2, KB3, KB4, and KB5 represent control scenarios corresponding to different infrastructure clusters, with the objective of operating the system to manage tidal intrusion and facilitate drainage within various clusters and sub-clusters. Simulation results are shown in Figures 11-13.

After the model validation criteria were satisfied, the simulated water level data at the sluices were used for the analysis of five scenarios. The simulation results indicate that the largest water level fluctuations occurred at Lung Tram, ranging from 1.16 to 1.37m; followed by the Vam Dinh area, with fluctuations between 0.8 and 1.21m, while at Bao Chau, water level variations ranged from 0.5 to 1.2m.

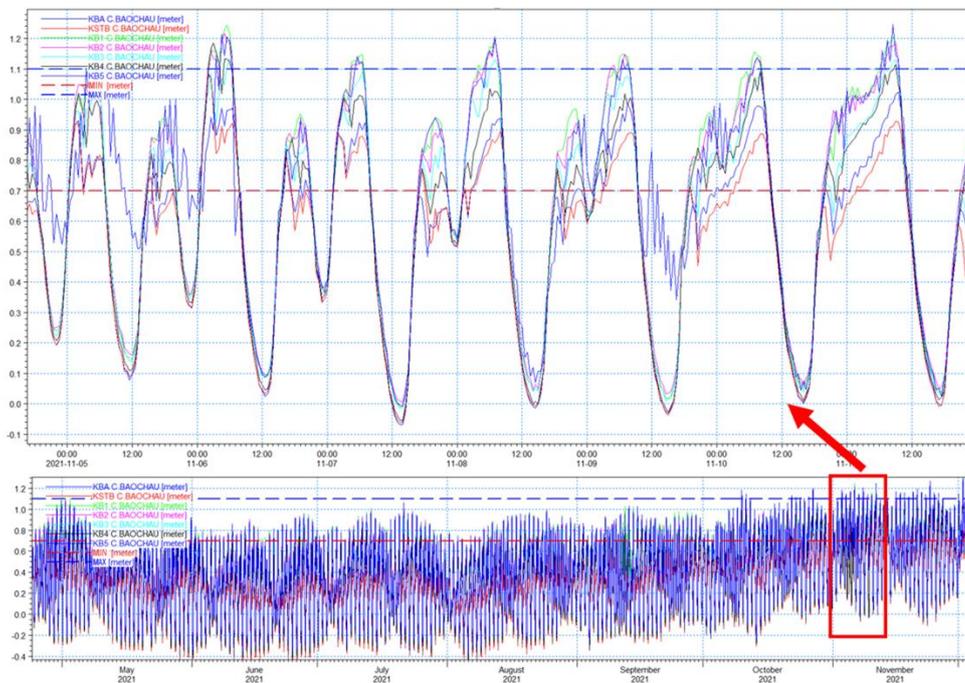


Figure 13. Simulated water level results at Bao Chau sluice gate

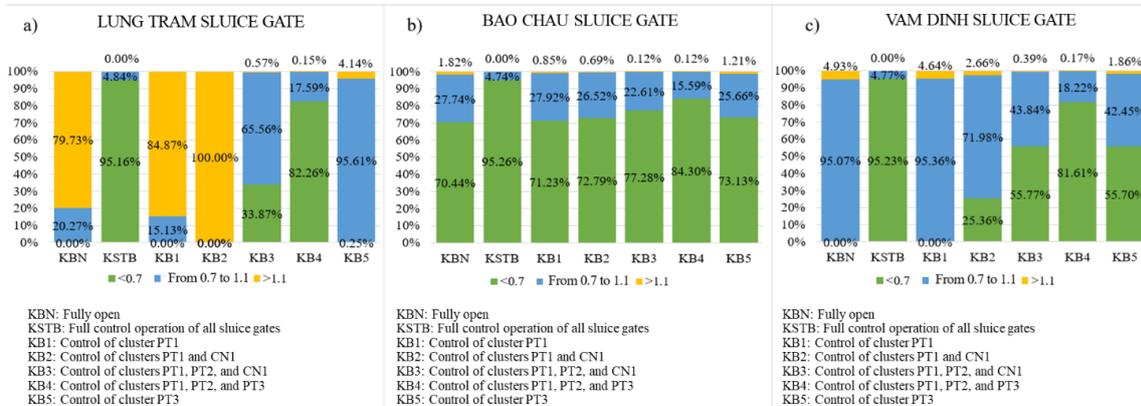


Figure 14. Results of the water level comparison analysis for the scenarios

According to operational guidelines from the Ca Mau Irrigation Management Center [18], the optimal water level for production ranges between 0.7m and 1.1m. Simulations for the rainy season of 2021 - a dry year with generally low water levels - indicate that most sluices in the study area maintained levels within or below the required range. However, sluices in Cluster PT2, particularly Lung Tram sluice, frequently exceeded the upper limit, with nearly 80% of water levels surpassing 1.1m and peaking at 1.372m. In contrast, other clusters rarely exceeded 1.1m (less than 5%), typically during tidal peaks in late October and November.

Under the full tidal control scenario (KSTB), water levels decreased significantly compared with baseline conditions, with over 90% of levels falling below 0.7m. This demonstrates the strong water-reduction effectiveness of full tidal control but indicates that such measures are unnecessary in dry years like 2021.

- KB1 and KB2: Limited control measures showed negligible differences from baseline.

- KB3: Controlling PT2 improved water regulation, reducing excess levels by nearly 80% in PT2; Lung Tram sluice experienced the largest reduction (up to 66cm).

- KB4: Simultaneous control of PT1, PT2, and PT3 significantly reduced water levels across all sluices, with reductions ranging from 58-117 cm.

- KB5: Controlling only PT3 proved effective, reducing water levels by 48-66 cm in PT1-PT3 and by 17-22 cm in CN1-CN2.

Figure 14 presents a comparative analysis of water levels across all scenarios, highlighting the relative efficiency and practicality of partial control strategies.

Notes:

- KS: Tidal control operation, when the water level at the Ganh Hao, Nam Can, or Song Doc boundaries exceeds Alarm Level 1, the sluices are closed to block tidal intrusion.

- M2C: Free two-way operation (sluices remain open for bidirectional flow).

- Tidal-Controlled Operation: the Bao Chau and Vam Dinh sluices are operated under tidal control based on the alarm water level at the Nam Can station, when the water level exceeds Alarm Level 1, the sluices are closed to block tidal intrusion.

4. Conclusion

This study comprehensively analyzed the current

status of agricultural production and irrigation system management in Sub-region X of Southern Ca Mau, integrating SWOT analysis and hydrodynamic modeling using MIKE 11 to propose effective operational strategies for sustainable water management. The findings provide critical insights into both the technical and institutional dimensions of irrigation system utilization under varying hydrological and tidal conditions.

From the SWOT analysis, it is evident that Sub-region X possesses significant inherent strengths. These advantages have enabled the expansion of aquaculture, which has achieved notable success in international markets under certification schemes such as VietGAP, ASC, and B.A.P. However, the study also identified several weaknesses, such as fragmented management, the absence of unified sluice operation protocols, and the predominance of traditional farming practices, which collectively limit production efficiency and adaptive capacity.

Opportunities for further development are substantial, simulation results from MIKE 11 revealed that operational management of sluice gates plays a decisive role in mitigating flooding and maintaining optimal water levels for agricultural production. Among the six analyzed scenarios, full tidal control proved highly effective in water level reduction but was determined to be economically inefficient and operationally unnecessary during dry years. Partial control strategies provided more balanced outcomes.

Overall, the study highlights that integrated management - combining physical infrastructure optimization, institutional coordination, and adaptive operational planning - can substantially improve the resilience and efficiency of irrigation systems in Sub-region X. The proposed framework serves as a valuable reference for decision-makers in developing flexible water control strategies that balance flood mitigation, aquaculture productivity, and transportation needs, thereby promoting sustainable agricultural development in the southern coastal areas of Ca Mau Province.

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