An application of 1-D model for assessing saline intrusion in the coastal areas of the Vietnamese Mekong Delta

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INTRODUCTION AND FIELD EXPERIMENTS

Many studies in present years have been conducted to predict the effects of changes in the upstream discharge, hydrodynamics, and saline intrusion in the coastal of the Vietnamese Mekong Delta (VMD) (Smajgl et al., 2015; T. Van et al., 2013); however, the models for the entire delta did not show detail for small areas such as the Ca Mau Peninsula, and other studies were only considered in upstream flooding condition such as the Long Xuyen Quadrangle (Nguyen et al., 2012; T. Van et al., 2013). Besides, several study were using hydraulic models for the whole VMD region; Nevertheless, these studies were only interested in major river systems that applied the Mike 11 salt simulation model for the VMD region. Some hydraulic studies were simulated in specific region such as Long Xuyen Quadrangle. However, a few studies have focused on a complex river system such as Quan Lo Phung Hiep (QLPH) area of the Ca Mau peninsula, which is characterized by a complex river system, inter-regional irrigation works, and a variety of water demands, including marine, brackish, and freshwater-based agriculture. However, coastal studies, particularly those of an inter-regional character with complicated river networks like the QLPH, have received little attention. As a result, this research was carried out to assess the hydrodynamics and saline intrusions of the interwoven river network's coastal area, a complex operating system in a large area affected by both tidal regimes in the West and East Sea, which is characteristic of the Mekong Delta. The study area is presented in Figure 1.

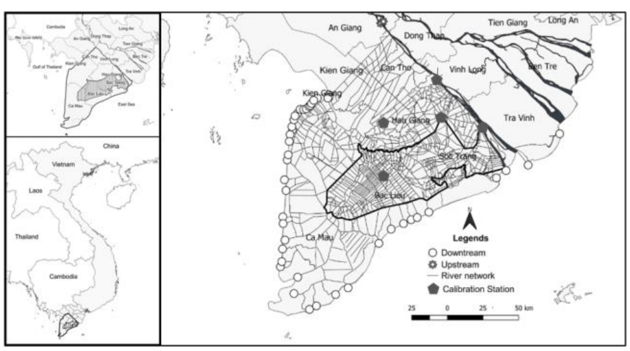

Figure 1 - The map of the study area (the thick black line in the map indicated for Quan Lo Phung Hiep).

METHODOLOGIES

MIKE 11HD setup

There are 2 upstream boundary conditions, characterized by measured water levels at Long Xuyen station and 44 downstream boundary conditions, grouped by four water level stations includes: at the Hau river mouth (Tran De) and other main river mouths (Ganh Hao, Rach Gia, and Song Doc) along the East and West Sea (Figure 1). The input data water level with time-series (one-hour time-step), were provided by the Southern station of Hydro-meteorological. The available data of the river network of QLPH including 932 rivers and canal segments, 13,164 cross-sections, and 154 sluice gate structures for water storage or saline intrusion control.

The model was calibrated and validated with data collected during the dry season (January to April) in 2016 and 2020, respectively according to five water level stations along the Hau River and river branches (including Phung Hiep, Vi Thanh, and Phuoc Long stations) (Figure 1). The model's boundary conditions were defined by the time series of water levels at the upstream and downstream points. In the hydraulic model, the roughness coefficient was the most influential and important parameter; therefore the Manning roughness coefficient was applied as the calibration parameter (Doncker et al., 2009; Rostam Afshar, 2013). The calibrating process was done based on the existing hydraulic roughness of the cross-section in the available deltaic model and adjusted gradually until the Nash-Sutcliffe index value (R^2) calculated according to the measured and simulated stage met the requirement. The calculated Nash-Sutcliffe index should be close to 1 (Dinh et al. 2012; Dang et al. 2013).

R Square formula:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left[Q_{obs,i} - Q_{sim,i}\right]^2}{\sum_{i=1}^{N}\left[Q_{obs,i} - \bar{Q}_{obs}\right]^2} \qquad (1)$$

Where: $Q_{obs,i}$, $Q_{sim,i}$: Simulated and measured data; and, $\bar{Q}_{obs}$: Mean measured data. Root Mean Square Error (RMSE) formula

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Simulation_i - Observation_i)}{N\ (Samples)}} \qquad (2)$$

RESULTS

Model calibration

Before the model is calibrated, a sensitivity analysis step should be done. Some study has suggested that a parameter of main importance is the roughness of the river channel and the banks. Here, the Manning coefficient is used as roughness parameter (Doncker et al., 2009; Garrote et al., 2021; Hameed & Ali, 2013). Therefore, in this study, we selected the Manning's roughness coefficients as the most sensitive parameter in the model, and then, should be used for the calibration. Model calibration is the process of estimating model parameters by comparing model predictions for a given set of assumed conditions with observed data for the same conditions.

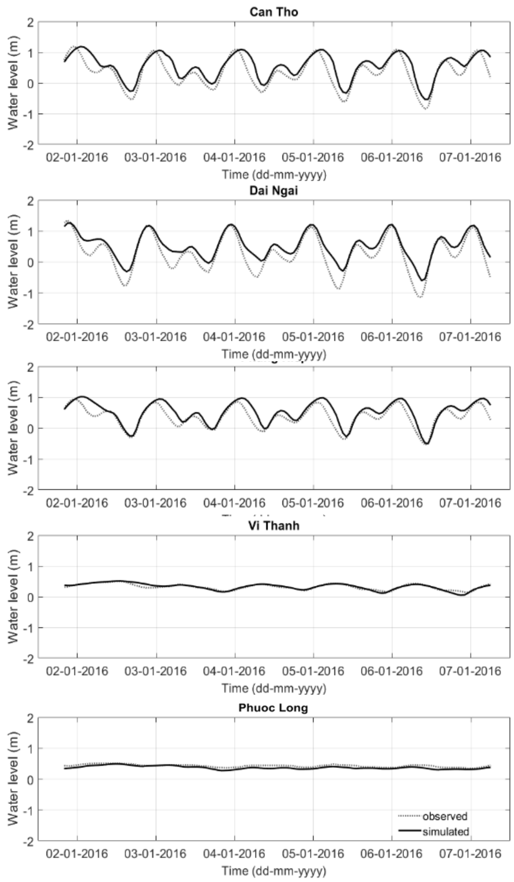

Figure 2 - Observed and simulated water levels at five locations in 2016. The left-hand side five panels represented for four months simulated and observed. The right hand side five panels indicated for one week simulated and observed. The grey dotted line presented for observed of the year 2016. The black line indicated for simulation of the year 2016.

Table 1- Performance indices obtained during calibration of Mike 11 HD model in the year 2016

Statistical variable	Can Tho	Dai Ngai	Phung Hiep	Phuoc Long	Vi Thanh
RMSE	0.37	0.44	0.28	0.32	0.05
R^2	0.86	0.84	0.85	0.85	0.88

Model validation

Test the hydraulic parameters that have been adjusted above using the 2020 dataset. Results of model testing at 5 stations are shown in Table 3. Through the results of calibration and validation, it shows that the simulated water level results are close to the actual measured value in terms of both absolute value and oscillation phase (with $R^2 > 0.8$). For validate the model simulation results, the R^2 values can be judged as satisfactory when they are higher or equal to 0.5 (Moriasi et al., 2007; P. Van et al., 2012). Thus, the calibrated and validated model Mike 11 can be used to continue simulating the river system in the study area under the assumption of the change of boundary conditions in the future.

Table 2 - Performance indices obtained during validation of Mike 11 HD model in the year 2020

Statistical variable	Can Tho	Dai Ngai	Phung Hiep	Phuoc Long	Vi Thanh
RMSE	0.34	0.42	0.22	0.36	0.09
R^2	0.88	0.82	0.89	0.89	0.88

CONCLUSIONS

The model was calibrated and tested with Manning's roughness coefficient n = 0.024 for the Hau river and n = 0.02 for the branch rivers. Furthermore, the correlation value (R^2) between the simulated and measured water levels of the model's process calibration and validation is all greater than 0.8, indicating that the model can be applied and used for the complex river systems in the VMD. Through this study, it is shown that a simulation model of hydraulic conditions in 2016 and 2020 on the main river system in the area of Quan Lo Phung Hiep has been built and this model has also been applied to forecast the future according to different scenarios of sea-level rise and reduced upstream discharge.

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