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Evaluation of salinity intrusion in the Southwest coastal zone of Vietnam

Nguyen Chinh Kien[a], Dinh Van Manh[a,b] and Hoang Van Lai[a]

[a] *Institute of Mechanics, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Hanoi*
[b] *VNU University of Technology, 144 Xuan Thuy, Hanoi*

Abstract

The Southwest sea of Vietnam, from Ca Mau Cape to the Cambodian border, including Phu Quoc and Tho Chu islands, has been especially interested and played an important role in the socio-economic development and national security of Vietnam. Requirements for understanding natural conditions, especially hydrodynamic characteristics and the marine environment for construction, mining, protection and integrated management of this area is urgently needed.

In recent years, there have been several investigations and researches within the framework of national research projects to provide an overview of the understanding or to solve specific problems in the area. However, the previous researches in details, including complex changes of seabed topography, morphology shore, marine estuaries / rivers were still not met the requirements.

In this report, a coupled 1-2D numerical model has been established to describe the characteristics of tides, currents and evaluate of salinity intrusion through river/canal system of the southwest coastal region.

Key Words: 1-2D numerical model, salinity intrusion, tide, Southwest sea of Vietnam

1. Numerical Modelling

In order to assess the salinity intrusion from the sea to inland river/canal system in the southwest sea of Vietnam a 1-2D coupling numerical model is established on the basis of the 1D and 2D Saint Venant equations as follows:

1D equations [1]

Hydraulic equations:

$$B\frac{\partial H}{\partial t} + \frac{\partial Q}{\partial x} = q \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left[\beta\frac{Q^2}{A}\right] + gA + \left[\frac{\partial H}{\partial x} + S_f\right] = 0 \qquad (2)$$

where, x and t denote space and time; A - the area of wet cross-section; B - the width of cross-section; H - water level; Q - discharge; β - momentum correction factor ($\beta \approx 1$); q - additional (or loss) discharge per unit length; S_f - friction slope (defined by the formula: $S_f = g|Q|Q/C^2R$ with R – hydraulic radius); and C – Chezy coefficient.

Mass conservation equation:

$$\frac{\partial A_t S}{\partial t} + \frac{\partial QS}{\partial x} = \frac{\partial}{\partial x}\left(A_t D\frac{\partial S}{\partial x}\right) + G(S) \qquad (3)$$

where S is pollutant concentration; D – diffusion coefficient; $G(S)$ – additional source.

2D equations [1]

Hydraulic equations:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x}(ud) + \frac{\partial}{\partial y}(vd) = 0 \qquad (4)$$

$$\begin{cases} \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial \zeta}{\partial x} - f\frac{u\sqrt{u^2+v^2}}{d} \\ \qquad + \Omega v + \frac{\tau_x}{\rho d} + D_h\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \\ \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial \zeta}{\partial y} - f\frac{v\sqrt{u^2+v^2}}{d} \\ \qquad - \Omega u + \frac{\tau_y}{\rho d} + D_h\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \end{cases} \qquad (5)$$

where, u and v are depth averaged velocity components in x and y directions respectively; ζ - water surface elevation; d - sea depth; $H = \zeta + d$ - total water column; Ω - the Coriolis parameter; g - gravity acceleration; τ_x, τ_y – wind stress components in x and y directions respectively (defined by $\vec{\tau}(\tau_x, \tau_y) = \rho_a C_d \vec{W}|\vec{W}|$ with $\vec{W}$ - the wind speed at 10 meters above the water surface (m/s); Cd - wind drag coefficient, ρ_a - atmospheric pressure; f - bed friction; and D_h - the horizontal viscosity diffusivity coefficient.

Mass conservation equation:

$$\frac{\partial(dS)}{\partial t} + \frac{\partial}{\partial x}(udS) + \frac{\partial}{\partial y}(udS) = \frac{\partial}{\partial x}\left(dD\frac{\partial S}{\partial x}\right) + \frac{\partial}{\partial x}\left(dD\frac{\partial S}{\partial x}\right) + G(S) \qquad (6)$$

where, D_s is horizontal diffusion coefficient.

Numerical solving techniques [2, 3]

In this paper, we use the finite difference method (FDM) to solve governing equations. The Preissman 4-points finite difference scheme is applied for 1D hydraulic equations (1) and (2), the up-wind scheme for the mass conservation equation (3).

For 2D equation system, the leap-frog scheme in time, the central or up-wind scheme in space are applied. Furthermore, grid patching technique is also included in.

On the above mentioned numerical solving techniques a computer program set are written in the Fortran language, using the parallel processing methods with the OpenMP standards-based Windows operating system [5].

The programs are built on with a graphical interface with GIS maps to display the results in real time.

Research area

The research area consists of two parts/regions: 1D and 2D regions. The 1D region is the rivers and canals of the Long Xuyen quadrangle, limited by Ha Tien, Chau Doc, Long Xuyen Rach Gia sections (as shown in Fig. 1). The river system consists of 425 river/canal sections with 1063 cross sections and 233 nodes [4].

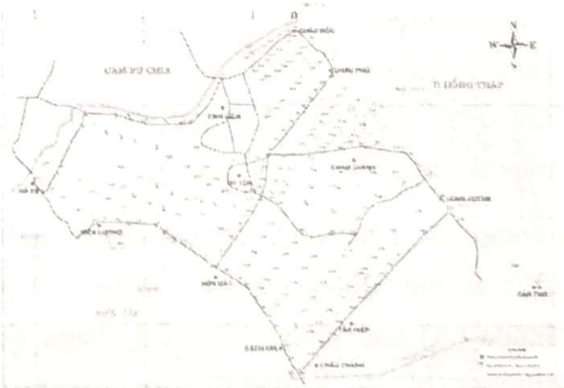

Fig. 1. 1D region

The 2D region is a southwest sea area as shown in Fig. 2. This sea area is covered by three nested grid with different grid sizes:

Grid 1 (finest): dimensions of 271 x 226 and grid size of 396m, includes southwest coast from Ha Tien to Rach Gia.

Grid 2: dimension of 151 x 118 and grid size of 1.188m, includes the entire Gulf of Rach Gia and Phu Quoc Island.

Grid 3: dimension of 105 x 226 and grid size of 3.564m, includes a rectangular region with two oceanographic stations: Camau and Chandaburi (where the harmonic constants are exploited for opened boundary conditions).

Fig. 2. 2D region

2. Numerical model verification

Calibration

It is impossible to get the observed data on currents/ discharges, the model parameters are calibrated by using the observed water levels at some locations only.

The comparison between the calculated results (Cal.) and the Observed data (Obs.) of the amplitude (A) and phase (G) of 4 major tidal constituents (M_2, S_2, K_1 and O_1) are presented in Tab. 1.

Table 1. Amplitude (A) and phase (G) of 4 major tidal constituents (M_2, S_2, K_1 and O_1) at Rach Gia and Ha Tien Stations (Cal.: calculation; Obs.: observation)

	A (cm)		G (°)	
M2	Obs.	Cal.	Obs.	Cal.
Rach Gia	14.21	14.2	96.23	108.6
Ha Tien	10	11.3	119	107.5
	A (cm)		G (°)	
S2	Obs.	Cal.	Obs.	Cal.
Rach Gia	2.46	2.6	145.88	150
Ha Tien	2	2	353	157.1
	A (cm)		G (°)	
K1	Obs.	Cal.	Obs.	Cal.
Rach Gia	17.01	16.6	73.08	74.7
Ha Tien	26	15.9	81	80.5
	A (cm)		G (°)	
O1	Obs.	Cal.	Obs.	Cal.
Rach Gia	9.7	8.2	44.76	18.5
Ha Tien	13	3.5	52	59.8

In Figs 3, 4 and 5, the calculated water levels at Rach Gia (in 2/2008 and 4/2008) and Long Xuyen stations are compared with the observed ones.

The comparisons show that the model is calibrated rather well not only in water level height but also in phase.

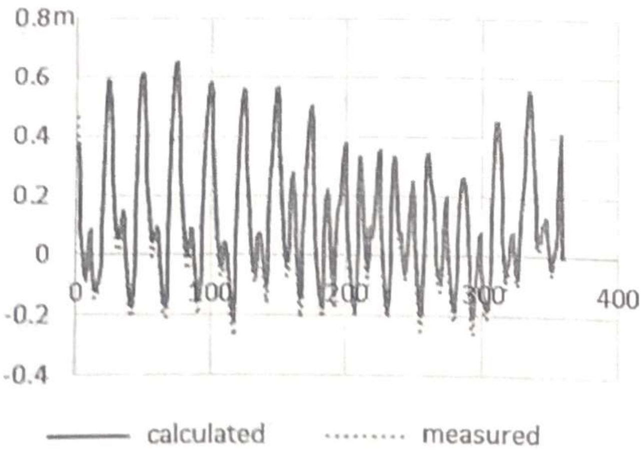

Fig 3. Calculated and measured water levels at Rach Gia station in 2/2008

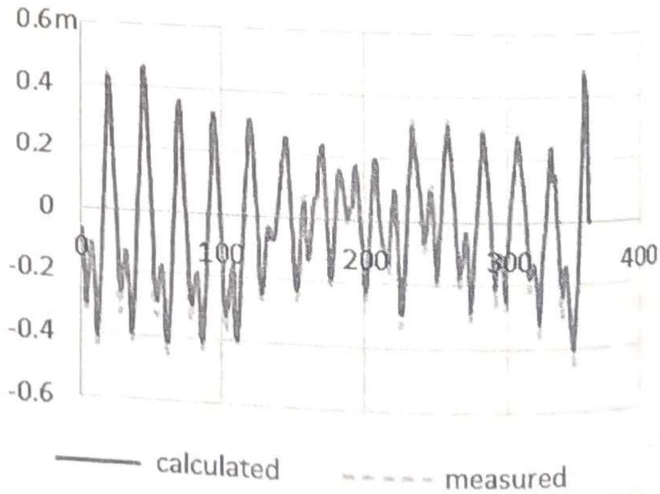

Fig. 4. Calculated and measured water levels at Rach Gia station in 4/2008

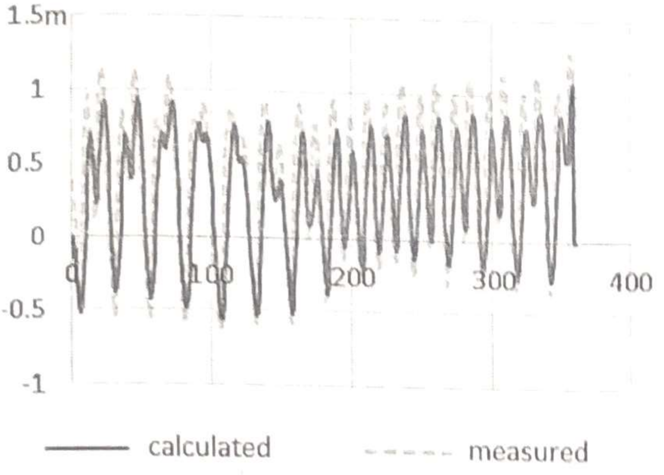

Fig. 5. Calculated and measured water levels at Long Xuyen station in 4/2008

Verification

In this research, measured data in 2010 and 2011 of some stations are used to verify the numerical model.

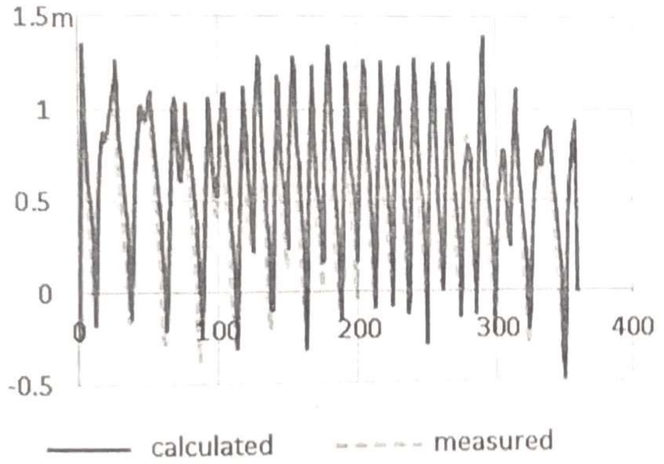

Fig. 6. Calculated and measured water levels at Chau Doc station in 2010

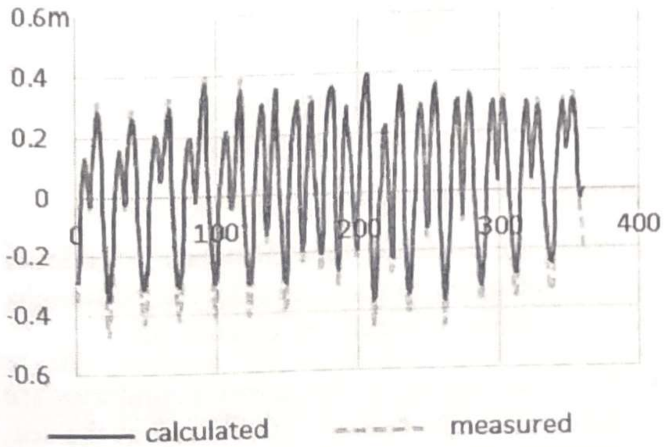

Fig. 7. Calculated and measured water levels at Rach Gia station in 2010

Figures 6 to 11 show that, there are a little difference between calculation results and measured data of water level at some stations. The comparisons show that, the numerical model is verified and ready to apply.

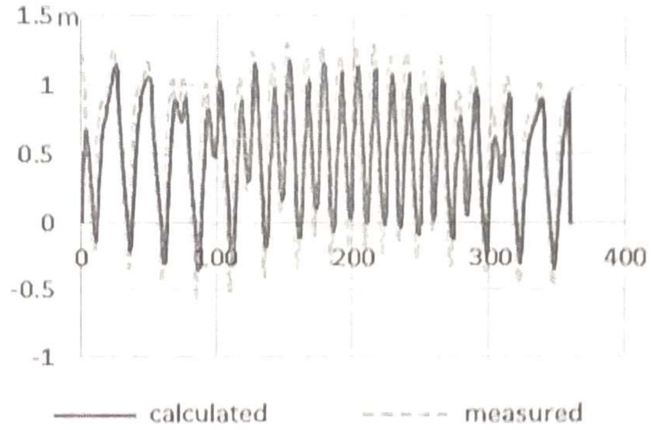

Fig. 8. Calculated and measured water levels at Long Xuyen station in 2010

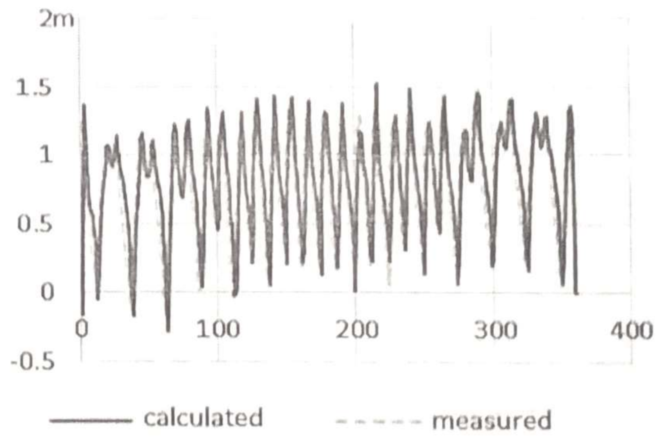

Fig. 9. Calculated and measured water levels at Chau Doc station in 2011

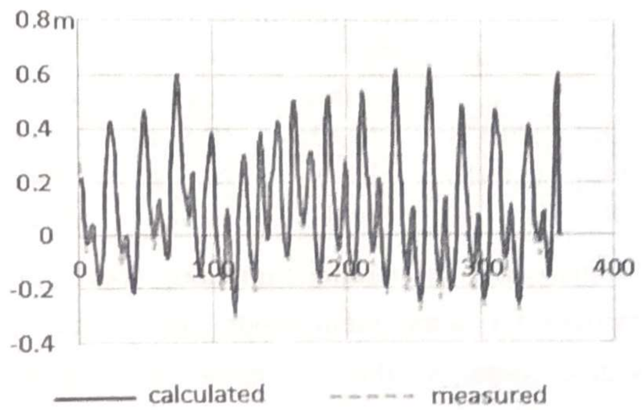

Fig. 10. Calculated and measured water levels at Rach Gia station in 2011

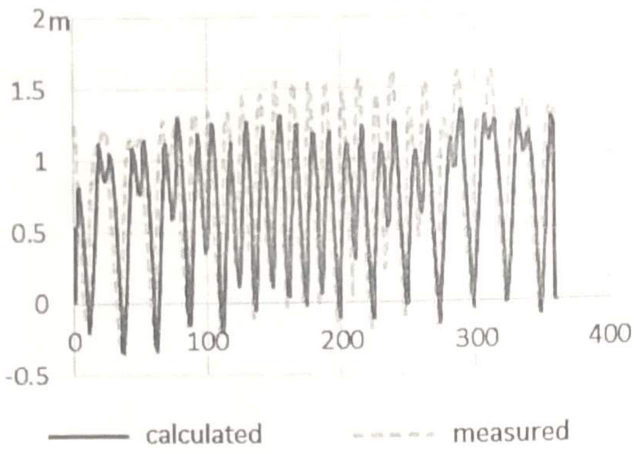

Fig. 11. Calculated and measured water levels at Long Xuyen station in 2011

Parallelizing

In efforts to reduce the CPU time, the program codes are modified to able to utilize the advantages of parallel processing technology. Because the time step in 2D region is quite small compared with the time step in 1D, furthermore, the computing mass for 2D regions generally are much more larger than that for 1D region, therefore, in this study only the 2D code part is paid attention.

The modified codes are tested: on 2 kinds of CPU: Intel Atom Z3740 1.8GHz 4-core and Intel core i7 3770 4.2GHz 4-core. The comparisons of time consuming in cases are presented in Table 2.

Table 2. Time consuming of sequential and parallel computation

PA	Atom Z3740		Core i7 3770	
	Seq.	OpenMP	Seq.	OpenMP
10h	200.52s	133.43s	38.65s	27.73s
20h	431.28s	311.49s	76.67s	54.48s
30h	606.24s	386.82s	114.80s	80.25s

In this study, the parallel computing codes only focused for some main loops, not for all of source codes. So the calculation speed of the numerical model can't be maximized as formulas of Amdahl's law [4]. However, Table 2 also shows the computation time of the model was reduced to 60-70%.

3. Salinity intrusion

It is very difficult to get the measured data in salinity in the studied area. There are only several measured salinity data in Rach Gia. However, it is not adequate to use for calibration. Therefore, only some test cases are carried out.

Case 2/2008

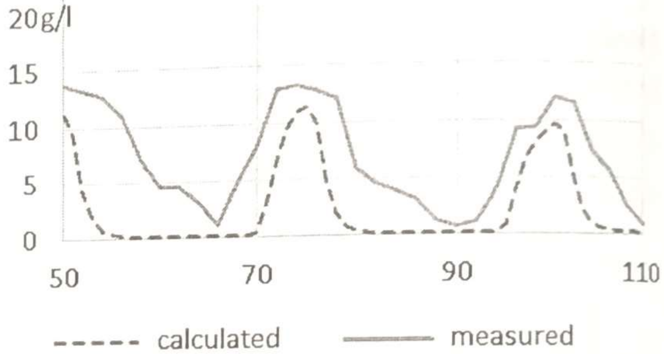

Fig. 12. Calculated and measured salinity at Rach Gia station in 2/2008

Case 2011

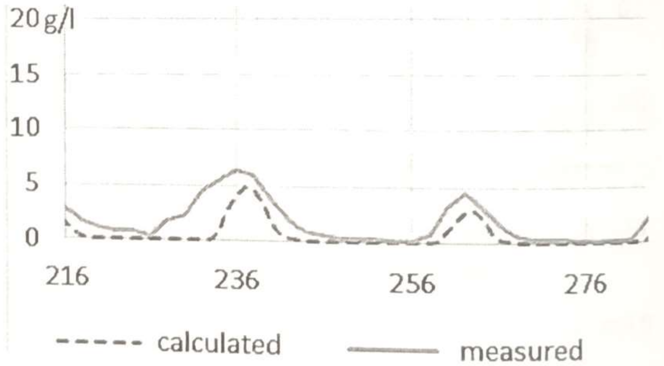

Fig. 13. Calculated and measured salinity at Rach Gia station in 2011

Salinity distribution in dry season

In order to evaluate the influence of tide to salinity intrusion in the Long Xuyen quarangle, two calculation senarios are carried out:

- River discharges at the upper boundaries are taken at in dry season (2008), and at the sea, water levels are spring tide.

- River discharges at the upper boundaries are the same values as the above case, but at the sea, water levels are neap tide.

Results are shown in Fig 14 and Fig 15.

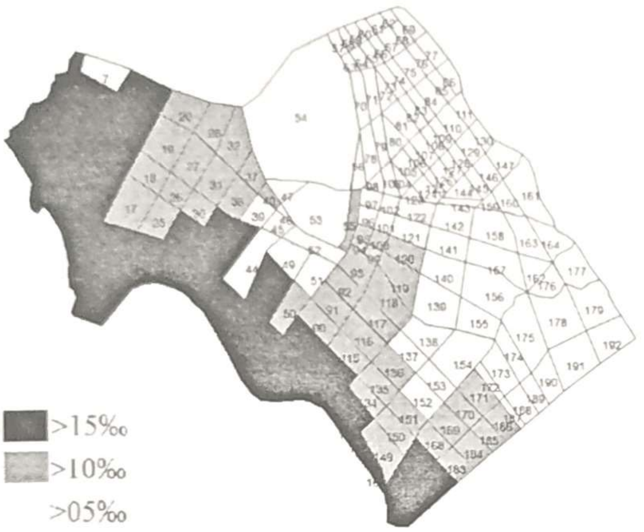

Fig. 14. Calculated salinity in the Long Xuyen quadrangle during spring tide

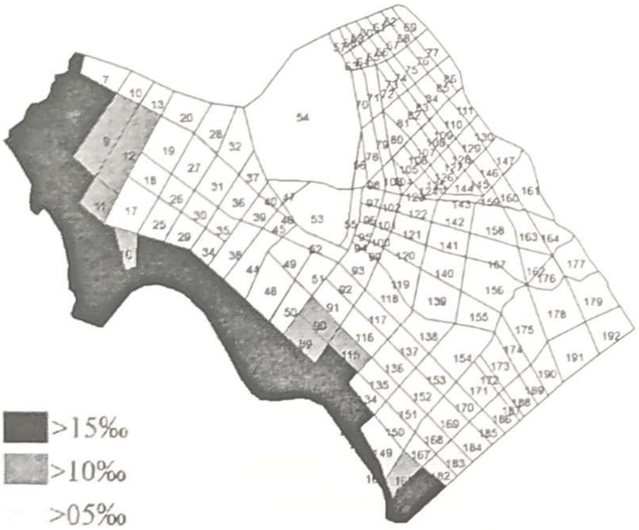

Fig. 15. Calculated Salinity in the Long Xuyen quadrangle during neap tide

In dry season, during spring tide, salinity intrudes far away from the coastline into the land. The salt water of more than 5‰ can appear at the location of 61.6 km from coastline. During neap tide, the salinity influence is less than that during spring tide, the maximum distance of the salt water of more than 5‰ is 24.5 km from coastline. That is agreed with the general salinity distribution in quality.

4. Conclusion

The 1-2D numerical model for calculating hydrodynamics and pollutant transportation has been established in the Long Xuyen Quadrangle and southwest coastal area. For hydrodynamics simulation, the numerical model has been verified rather well, but because of lack of the measured data on salinity only some test cases are carried out

In order to apply the numerical model to study hydrodynamics and water quality in the area, it is necessary to get some more measured data, especially salinity, in order to verify the model.

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4) http://en.wikipedia.org/wiki/Amdahl's_law.

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