Assessing the Environmental Impacts of the Artificial Navigation Channel in Southern Vietnam

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Abstract. The new Hau's entrance navigation route (known as "bypass project") has been kicked-off in Tra Vinh province with aim to increase the availability of waterway traffic in the Mekong delta. The improvement project includes with existing Quan Chanh Bo channel and 8 km of artificial channel was 1st launched in 2017. After years of operation, the project has taken its effects on the movement of the large cargo vessel to the inland ports. However, with immense biological risks identified, riverbank erosion coupled with the risk of deposition has raised questions to governments and scientists about its viability. This paper analyses the environmental impacts of the navigation channel in context of bank stability and sedimentation discharge. It was shown that, digging of new canal has significantly affected the current velocity at the river mouths. It is also found that, increasing of the movement through navigation channel is expected to increase the risk of bank erosion and sediment deposition in simulated volume of sediment discharged is 691.483 m^3/year.

Keywords: Bypass project · Artificial canal · Ship-generated wave · Bank erosion · Sediment transport

1 Introduction

Several years ago, the waterway traffic through Mekong river to inland ports (Hau Giang, Can Tho, An Giang) has increased rapidly. However, the main entrance route through Dinh An estuary is usually interrupted by high rate of deposition [2]. Risk of grounding has led the low availability of the waterway system. To increase the uptime of the navigation system, the By-pass project was begun in 2005 in the Tra Vinh provinces. The workscope of By-pass project, phase 1 includes with digging of 8.7 km new canal (bypass canal), dredging of 7.7 km of bypass estuary and modification of 20 km of existing Quan Chanh Bo channel (QCB) to allow the large cargo vessels up to 10,000 DWT to enter the inland ports (Fig. 1).
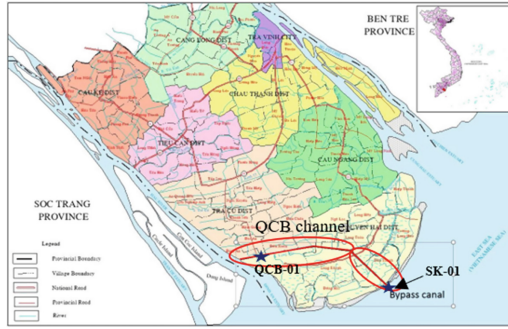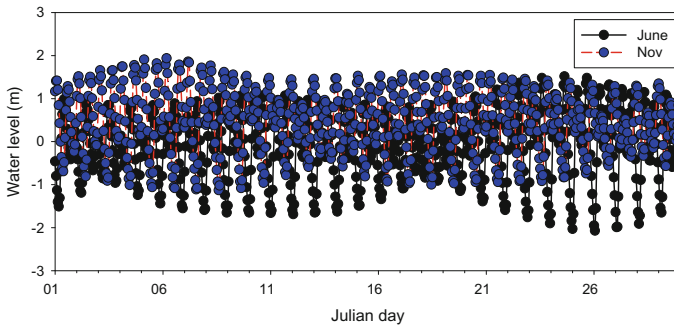
Fig. 1. Map of study area

Fig. 2. Measured water level at Dinh An estuary

After years of operation, the artificial project has taken its effect on the provision of smooth operation of the thousands means of transportation. Besides of positive effects on waterway traffic, bypass projects has several social encounters as well as environmental issues [6, 7, 9, 10]. The objectives of this paper are to analyze and identify the potentially environmental impacts of the bypass projects which could affect on the project feasibility in further phases.

Study area is affected by both tidal condition of the Mekong river and Vietnamese East Sea (Fig. 2).

2   Methods

2.1   Field Survey and Investigation

The aim of site survey is to investigate current state of the bank erosion and soil investigation. There were total 102 boreholes were taken. Samples shall be experimentally analyzed in the laboratory to determine the grain size distribution and physical characteristic of the bank material which effects on the eroding resistance of the riverbank [1, 5] (Fig. 3).

Fig. 3. Soil samples and laboratory analysis for bank material characteristic

2.2 Wave Measurement

To evaluate the potential impacts of the ship generated waves, the wave measurement metering has been conducted at the SK-01 in the bypass estuary and QCB-01 in Quan Chanh Bo channel (Fig. 4). The purpose of site monitoring is to measure the wind-wave and ship generated wave at the project area.

Fig. 4. Site wave measurement using AWH-Infinity

The maximum wave height created by a ship can theoretically be estimated as:

$$H = \frac{U^2}{g}\beta(F_* - 0.1)^2\left(\frac{y}{L_s}\right)^{-1/3} \tag{1}$$

where: H = wave height (m); U = ship velocity relative to water velocity (m/s); g = acceleration due to gravity (m/^{2}); β = dimensionless coefficient dependent on ship entrance length; y = distance from sailing line (m); L_s = ship overall length (m).

The orbital velocity of the linear wave is defined by:

$$U_{orb} = \frac{\pi H}{T * \sinh(2\pi h/L)} \tag{2}$$

where: U_{orb} = wave orbital velocity near the bed (m/s); H = wave height (m); T = wave period (s); L = wave length (m) and h = SWL depth (m). The wave friction factor is defined by the relationship of length scale A = (U_{orb}*T)/2π (m) and roughness z_0 (m) as $f_w = 1.39\left(\frac{A}{z_0}\right)^{-0.52}$ (Soulsby 1997).

The bed shear stress from oscillatory flow alone is defined by, among others, Voulgaris et.al. (1995), modified by Soulsby (1997) define the wave orbital velocity as:

$$\tau_w = \frac{1}{2}\rho f_w U_{orb}^2 \tag{3}$$

where: τ_w is the wave averaged bead shearstress (N/m^2); ρ is the density of water (kg/m^3); f_w is the wave friction factor and U_{orb} is the wave orbital velocity near the bead (m/s).

2.3 Numerical Modelling

In this paper, the MIKE (by DHI) numerical computing model has been applied to evaluate the potential impacts of the artificial projects on the hydrodynamic regime. Scenario models have been established to simulate the normal and completed projects condition varying the dry and rainy season. Typical input for the numerical model is given in Table 1 while selected monitoring points are graphically illustrated in Fig. 5.

Table 1. Input data for numerical model

Parameters	Value	Sources/Note
Topography	1:50000	US Army (1987); VN Naval agency (2009) and dredging project data (2015)
Water level	Hourly data	Global tidal model; My Thanh Station
Wave	Hourly data	Measured data
Sediment	$D_{50} = 0.2$ mm	Site sample analysis data
Discharge	Hourly data	Measured data

The govern equation of hydrodynamic model is based on Average-based Navier-Stoke for the shallow water.

$$\frac{\delta h}{\delta t} + \frac{\delta u}{\delta x} + \frac{\delta hv}{\delta y} = hS$$

$$\frac{\delta hu}{\delta t} + \frac{\delta hu^2}{\delta x} + \frac{\delta hvu}{\delta y} = fvh - gh\frac{\delta\eta}{\delta x} - \frac{h}{\rho_0}\frac{\delta p_a}{\delta x} - \frac{gh^2}{2\rho_0}\frac{\delta\rho}{\delta x}$$
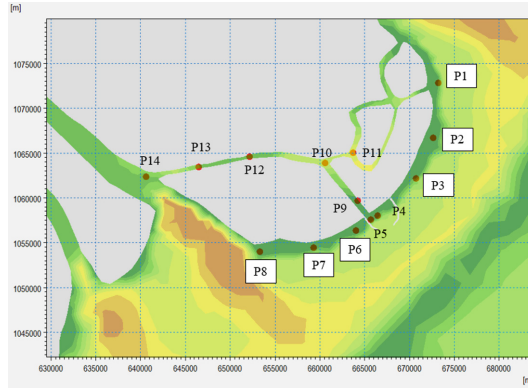
Fig. 5. Finite mesh for the hydrodynamic model and monitoring points extracted from the simulation

$$+ \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} - \frac{1}{\rho_0}\left(\frac{\delta s_{xx}}{\delta x} + \frac{\delta s_{xy}}{\delta y}\right)$$

$$+ \frac{\delta}{\delta x}(hT_{xx})$$

$$+ \frac{\delta}{\delta y}(hT_{xy}) + hu_s \tag{4}$$

$$\frac{\delta hv}{\delta t} + \frac{\delta huv}{\delta x} + \frac{\delta hv^2}{\delta y} = fuh - gh\frac{\delta \eta}{\delta y} - \frac{h}{\rho_0}\frac{\delta p_a}{\delta y} - \frac{gh^2}{2\rho_0}\frac{\delta \rho}{\delta y}$$

$$+ \frac{\tau_{sy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} - \frac{1}{\rho_0}\left(\frac{\delta s_{yx}}{\delta x} + \frac{\delta s_{yy}}{\delta y}\right) + \frac{\delta}{\delta x}(hT_{xy})$$

$$+ \frac{\delta}{\delta y}(hT_{yy}) + hv_s S \tag{5}$$

where: t is the time; η is the differential of water level; d is the water depth; u, v are the horizontal and vertical velocity; $f = 2\Omega\sin\phi$ is the coriolis parameter; ρ is the density; ν is the kinematic viscouscity; S is the income flow with u_s, v_s are the component velocity to the area.

The cohesive sediment transport model is deals with the movement of mud in a fluid and interaction between of the mud and the bed. The governing equation for mud transport with the impact of waves and bed shearstress are based on Mehta et al. (1989) while deposition is defined as Krone (1962).

$$\frac{\partial c^i}{\partial t} + \frac{\partial uc^i}{\partial x} + \frac{\partial vc^i}{\partial y} + \frac{\partial wc^i}{\partial z} - \frac{\partial w_s c^i}{\partial z} = \frac{\partial}{\partial x}\left(\frac{\vartheta T_x}{\sigma_{Tx}^i}\frac{\partial c^i}{\partial x}\right)$$

$$+ \frac{\partial}{\partial y}\left(\frac{\vartheta T_y}{\sigma_{Ty}^i}\frac{\partial c^i}{\partial y}\right)$$

$$+ \frac{\partial}{\partial z}\left(\frac{\vartheta T_z}{\sigma_{Tz}^i}\frac{\partial c^i}{\partial z}\right) + S^i \tag{6}$$

where: x, y, z are the Certesian co-ordinates; u, v, w are the flow velocity components; c^i is the ith scalar component which is defined as the mass component; w is the settling velocity; $\sigma^i_{Tx,y,z}$ are the turbulent Schmidt nunber; $\vartheta T_{x,y,z}$ are the anitropic eddy viscosity and S^i is the source term.

$$D = w_s c_b p_d \tag{7}$$

where: $w_s = k \left(\frac{c}{\rho_{sed}} \right)^\gamma$ is the settling velocity ofsuspended sediment. k is a experimental constant; ρ_{sed} is the sediment density; c is the sediment concentration and γ is the coefficient termed settling index. If $c < c_{floc}$, the settling velocity and k is the constant; c_b is the suspended sediment concentration near the bed; and $p_d = 1 - \frac{\tau_b}{\tau_{cd}}$ is the desposition probability.

The numerical results were verified by the NASH which determines the model accuracy by the simulated results and observation data.

$$\eta = 1 - \frac{\sum_{i=n}^1 (H_{obsi} - H_{simi})}{\sum_{i=n}^1 \left(H_{obsi} - \overline{H_{obsi}} \right)} \tag{8}$$

where: H_{obsi} and H_{simi} are the ith observation and simulation data; $\overline{H_{obsi}}$ is the average observation data. The NASH coefficient for the water level at June and November were 0.96 and 0.87, inrespectively.

3   Results

3.1   Bank Erosion State at QCB Channel

Figure 6 captures the current bank erosion at QCB channel in Jul 2020. It was shown that, most of the riverbank is now being eroded seriously. Eroding has threatened the living of the public residence area, agricultural farms, and bank protection structure.

Fig. 6. Bank erosion state at QCB channe

3.2 Ship-Induced Wave Measurement

Figure 7 illustrates the recorded data from the wave characteristics at the bypass canal estuary (SK-01). The normal wave (wind-wave) has the lower height than ship-induced wave. At the SK-01, the normal wave height varies from 0.2—0.65m where the ship-generated wave peak at 1.4m. Similar, normal wave height in the QCB-01 is 0.1–0.2 m while ship-induced wave is over 0.35m (Fig. 8). Figure 9 records the wave distribution generated by 5,000 DWT cargo ship.
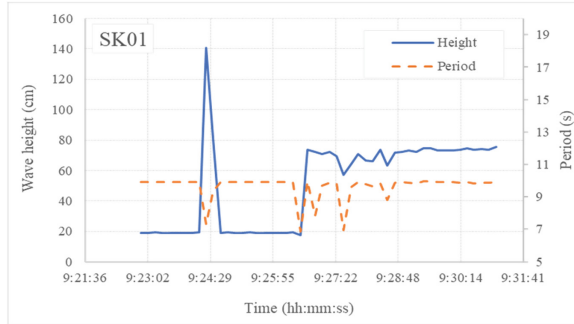

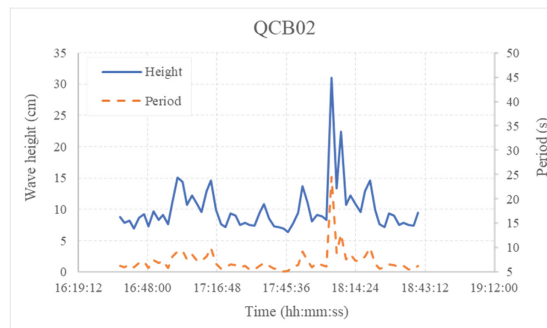**Fig. 7.** Ship-induced wave measured at the Bypass estuary

Fig. 8. Ship-induced wave measured at the QCB channel

3.3 Current Impacts

Figure 10 presents the change on current distribution with impacts of the artificial navigation channel. It is found that the artificial canal has affected on the local hydrodynamic significantly. Table 2 summaries the current impacts of the artificial canal. It was witnessed the significant change on current velocity at connecting points (P5, P10 and P14). At the bypass estuary (P5), the current speed increased by 0.46 m/s in the rainy season and 0.57 m/s in the dry season. High speed of current shall impact on the coastal erosion at Dan Thanh (Northside) and Dong Hai commune in the Southside. In addition, current

Fig. 9. Ship-generated wave recorded in QCB on 05th August 2020

speed at Dai An (P14) has significantly increased due to effect of the artificial canal. Maximum velocity at this point is lower to 1.34 m/s (in rainy season) and 0.97 m/s in the dry season. High velocity of current is over the eroding resistance of the cohesive bank causing the bank erosion.
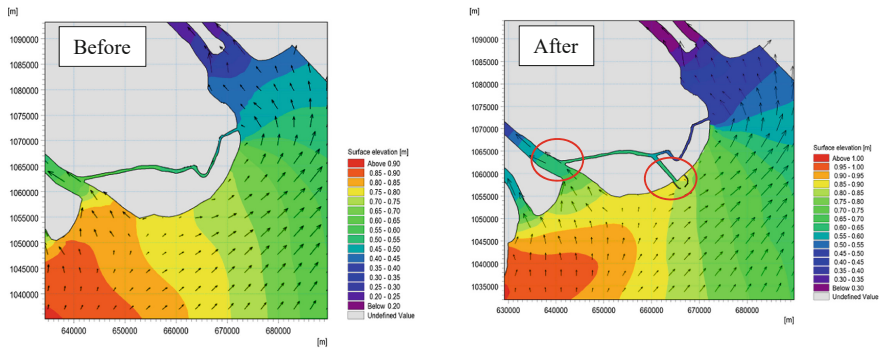

Fig. 10. Change on current velocity due to artificial navigation channel

3.4 Sediment Transport

Sediment transport is one of the most concern of the Hau river which has significant impacts on the movement of the cargo vessel. Due to the artificial channel, the movement of sediment source has changed significantly. Sediment flows shall be shared to QCB channel and flows to the sea through bypass canal. Figure 11 presents the simulated results on sediment discharge in the rainy season.

Table 3 compares the impacts of the bypass project on the rate of bed level change at the selected monitoring points. It was seen that, due to the bypass canal, sediment flow

Table 2. Summary the changes on current speed due to project

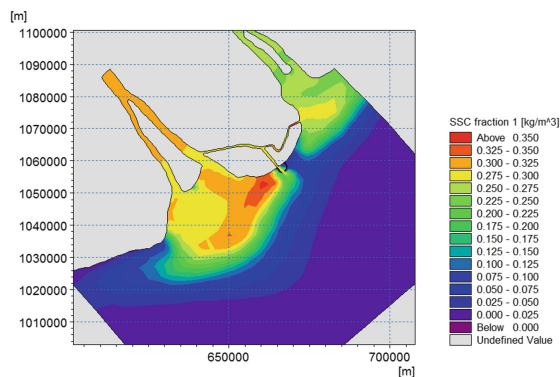| No	Name	Position (m)		Rainy season (June)			Dry season (Nov)		
		X	Y	Before	After	±	Before	After	±
P1	Truong Long Hoa	673204	1072833	0.35	0.26	−0.09	0.34	0.23	−0.11
P2	Ba Dong beach	672632	1066677	1.12	0.46	−0.66	0.94	0.43	−0.50
P3	Dan Thanh 1	670697	1062148	0.88	0.53	−0.35	0.74	0.41	−0.32
P4	DH1 Power plant	666432	1058015	0.39	0.77	+0.39	0.27	0.48	+0.21
P5	Bypass Estuary	665685	1057575	0.45	0.92	+0.46	0.26	0.83	+0.57
P6	Dan Thanh 2	664014	1056344	0.55	0.74	+0.20	0.46	0.47	+0.01
P7	Dong Hai 1	659309	1054454	0.63	1.02	+0.39	0.47	0.66	+0.19
P8	Dong Hai 2	653329	1054014	0.64	1.07	+0.43	0.38	0.78	+ 0.39
P9	The 913 Ferry	664190	1059686	0.58	0.49	−0.09	0.42	0.52	+0.10
P10	QCB-Bypass canal	660584	1063907	0.63	0.64	+0.01	0.42	0.62	+0.20
P11	Long Toan	663706	1065006	0.69	0.67	−0.02	0.34	0.65	+0.21
P12	La Ban canal	652186	1064611	0.84	0.58	−0.26	0.64	0.60	−0.04
P13	Lang Sat Ferry	646470	1063467	1.29	0.65	−0.64	0.95	0.68	−0.27
P14	Dai An	640578	1062368	0.67	1.34	+0.67	0.47	0.97	+0.50

Fig. 11. Simulation results on sediment transports

Table 3. Comparison on rate of bed level change.

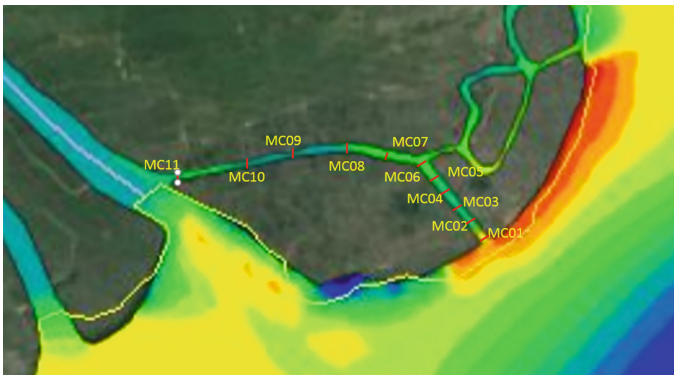| Location	Rainy season (June)	Dry season (Nov)
P1	+4%	+3%
P2	−3%	−1%
P3	−3%	+0%
P4	−11%	+2%
P5	3%	+5%
P6	−8%	+0%
P7	+22%	+1%
P8	−3%	+12%
P9	+16%	+17%
P10	−1%	−1%
P11	−24%	−1%

Fig. 12. Cross-sections to determine the volume of sediment discharge

has trend to supply the southern side (Dong Hai commune) while the rate of bed level change on the North side is reduced.

To determine the overall deposition volume, the navigation route is divided into 11 sections shown in Fig. 12. Table 4 presents the calculated volume of sediment through cross-section along the navigation route. It was found that total volume of sediment through the navigation channel is approximately 691,483.22 m^3.

4 Discussion

Bypass navigation project has taken its effect on reducing the risk of grounding on Dinh An estuary, allowed the large cargo vessel to enter the inland ports smoothly. However, negative environmental impacts of the project should be considered seriously. In this

Table 4. Calculated sediment deposition on the artificial navigation channel.

Section ID	Mass of discharge between 2 sections (m^3)	Accumulated discharge (m^3)
MC1	0	0
MC2	61,157.14	61,157.14
MC3	63,610.36	124,767.5
MC4	65,827.21	190,594.71
MC5	67,249.53	257,844.24
MC6	67,603.47	325,447.71
MC7	68,917.58	394,365.29
MC8	71,784.06	466,149.35
MC9	70,426.27	536,575.62
MC10	76,364.37	612,939.99
MC11	78,543.23	691,483.22

paper, the author has combined the field survey and numerical model to identify the potential impacts of the artificial system on the bank erosion. The results have pointed out three main factor which may lead the unexpected problem are change on current velocity, ship-generated wave, and risk of deposition at the bypass canal.

Due to the bypass canal, current speed at the new estuary and Dai An has significantly changed. Maximum current speed at the new estuary is 0.92 m/s. Increasing of the current speed pushed a pressure on the bank stability at Dan Thanh and Dong Hai commune. Otherwise, the presence of bypass canal has led the current speed at Dai An decrease rapidly by over 0.5 m/s.

Meanwhile, the artificial project shall lead the movement of cargo ship through QCB channel to be increased which leads the risk of bank erosion. Measured ship-generated wave at QCB channel varies in range of 0.35–1.4 m which generates a shear stress on the cohesive bank structure.

In addition, bypass canal shall increase the sediment flow through QCB channel and new artificial canal. Sediment flow from Hau river shall be shared by artificial canal. Estimated volume of sedimentation through new nvigation channel is approximately 691,483 m^3/year.

5   Conclusion

This paper has identified the environmental impacts of the bypass canal on bank erosion at QCB channel and surrounding areas. It is found that three main factors impacted by new navigation route are current speed, ship-generated wave, and risk of deposition from the sediment flow shared from Hau river. However, with immense biological risks identified, riverbank erosion coupled with the risk of deposition have raised questions to governments and scientists about its viability. Besides, estimated volume of deposition is

691,483.22 m^3/year. Therefore, it is required the master plan on operation, maintenance, and dredging activities to ensure the effectiveness of the navigation route.

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