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Hydrodynamic Modeling on the Secondary Channel of Irrigation Tidal Unit at South Kalimantan (Case Study of Agriculture Reclamation Tidal of Terantang Unit)

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ABSTRACT

Pond agriculture tide is a combined freshwater, salinity and the result of agricultural activity. Nowadays, parts of the irrigation area especially secondary channel at agricultural tidal pond (with shallow water) was related to the movement of water flow. Therefore, the main important stage to study is analysis of flow and velocity pattern. Flow pattern at agricultural tidal pond was mostly influenced by input of water on tidal movement and effect of wind. In addition, velocity of wind would generate shear forces on the water surface that would push the water mass and create the flow movement. The flow and velocity pattern could be examined by utilizing a two dimensional (2-D) hydrodynamic numerical model. The model was based on numerical solution of continuity and momentum equations which was solved with finite different method that was Mac Cormack method. The validity of model was tested with experimental model of 2-D stream flow simulations with rectangular shape. The experiment was applied to the secondary channel of irrigation tidal unit in South Kalimantan and it had given satisfactory of result. Result showed that flow velocity characteristic of tide and ebb water at estuary and the end of channel was not the same, then Flow pattern and velocity would be able to predict the pattern of sediment transport and the otger pollutant.

Keywords: hydrodynamic, numerical model, shear force, flow pattern

INTRODUCTION

Area of tidal swamp in Indonesia, especially in some provinces of Kalimantan island was very large and potential to develop seriourly. That was approximate 1 million hectares of swamp area resides in there. This potency was a very valuable asset for agricultural feature, and plantation [1]. Parts of coastal zone on islands of Indonesia was as wide field area which had not been productive. There were some efforts carried out in the usages of plantation, fishery, and agriculture. Agriculture at coastal area with low topography was influenced by tidal water. In the effort of development of agricultural or fishery area at coastal area, the usage of coastal area for agriculture was carried out by controlling tidal water. This control system was known as one way or two way, which had multi function systems. One of the functions was the water surplus could be stored in tidal pond. The result of drained water could be drained when ebb condition. Therefore it was flowed return to estuary for sirculation of water. It meaned that tidal stream would take fresh water mass and it could be pushed together with polluted water towards to estuary when ebb condition. Pollutant of water was caused by the activity of agricultural working, element of hara, and the others pollutant at management of macro waters and tidal pond like bacteria, plancton, and sediment which was moving by tidal and ebb water. It would decrease water quality and destroy fertility of vegetation and aquatic life.

Tidal pond and secondary channel with shallow waters, relatively wide, and had unsteady non uniform flow, the velocity and direction of water would change due to time and space. Stream movement was as an aeration process, which was oxygen was entering into water body with the quantity based on the number of the stream velocity. Therefore the content on water quality of parametre at every point of stream area would not be in average. Therefore the characteristic of water quality was always changed and depends on stream velocity when ebb-tidal condition was caused by wind turbulence.

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Theoritically, result of measuring of stream velocity at the field would be accurate if it was measured at each certain distance and interval of time during the process of ebb-tidal or caused by wind turbulence. But this method needed a long time and expensive cost. One of the economical alternatives was to develop model of numerical hydrodynamic in monitoring stream pattern and the velocity at secondary channel and tidal pond. This model could monitor stream pattern and flow velocity at every point of flow area and at the certain time at secondary channel and tidal pond. In addition, based on the stream pattern and flow velocity, it is predicted the quantity and the pattern of pollutant concentration at every point of flow area too.

The theoretical coefficient of momentum and energy had to be evaluated before one could accurately use the cross section averaged equations of momentum and energy in two-dimensional (2-D) flow computation [2]. Hydrodynamic equation was generally solved by explicit Mac Cormack method. Validity of this two dimensional (2–D) numerical model had been verified by comparing the result to the stream flow measuring and would give satisfactory result [3].

MATERIALS AND METHODS

Location of study was at 60 km north side of Banjarmasin City. Map of location was as in Figure 1 below

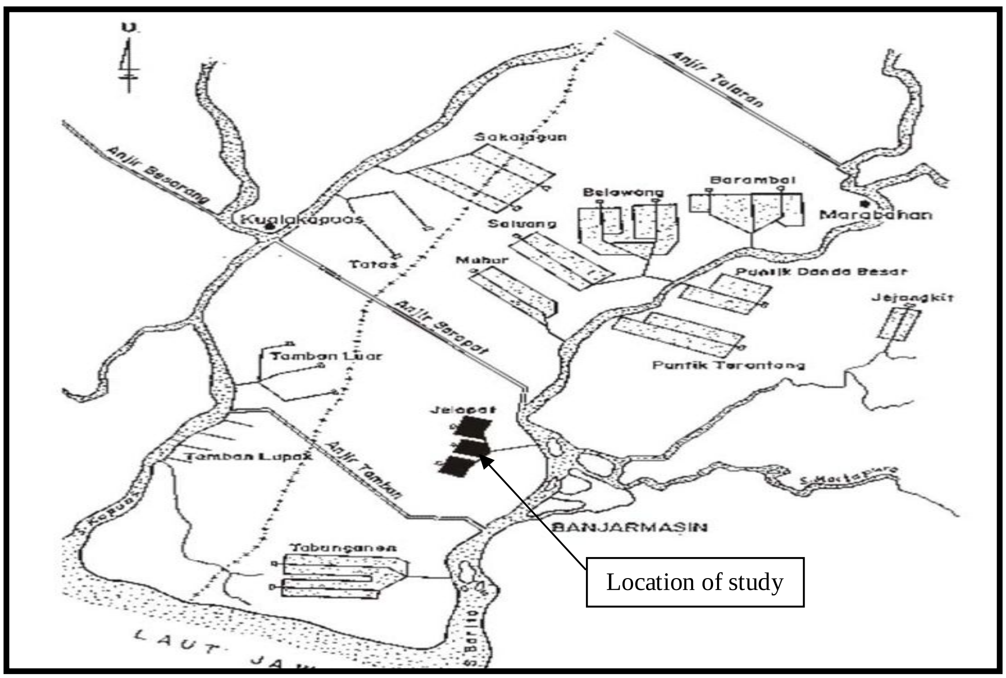

Figure 1 Map of Location

Before building the hydrodynamic model, it was carried out some steps to identify existing condition and to prepare the data input as follow:

1. To identify the problems included ebb-tidal, hydro-topography, and agricultural water system. Ebb-tidal was used to evaluate the fluctuation of ebb-tidal. Observation of hydro-topography and agricultural water system were conducted at secondary channel to determine channel geometric of hydraulic parameter. The results above was needed as input of hydrodynamic model.
2. To built hydrodynamic model based on data input and governing equation like continuity and momentum.
3. To carry out simulation of model and then applying the model.

Governing Equations

The basic equations used in the hydrodynamic models were conservation of fluid mass equation and momentum equations. The equations were first developed in three-dimension. By depth averaged integration, the equations were reduced into two-dimensional equations which were suitable for the shallow depth estuaries, lagoon, or primary canals, and secondary canals of irrigation in South Kalimantan. Procedure of the formulation wass similar to Mac Cormack. The alternating direction explicit method was used to solve the partial differential equations. The governing equations were as follow: [4][5][6]

Continuity equation:

$$\frac{\partial H}{\partial t} + \frac{\partial}{\partial x}(UH) + \frac{\partial}{\partial y}(VH) = q$$

Momentum equation at y direction:

$$\frac{\partial}{\partial t}(VH) + \frac{\partial}{\partial x}(\beta UVH) + \frac{\partial}{\partial y}(\beta VVH) = -gH\left(\frac{\partial H}{\partial y}\right) - gHS_{oy} - gHS_{fy} + \frac{\tau_{wy}}{\rho}$$

Momentum equation at x direction:

$$\frac{\partial}{\partial t}(UH) + \frac{\partial}{\partial x}(\beta UUH) + \frac{\partial}{\partial y}(\beta UVH) = -gH\left(\frac{\partial H}{\partial x}\right) - gHS_{ox} - gHS_{fx} + \frac{\tau_{wx}}{\rho}$$

Characteristic method

This method was as the solution of boundary condition at upstream and downstream. The using of explicit method of Mac Cormack could be solved if the initial and boundary condition were known. Characteristic method [7][8][9] was used to solve the solution of this flow boundary. Boundary condition at secondary channel of tidal agriculture is presented in Figure 2. Boundary condition at upstream were as opened boundary and the data was water depth of ebb-tide, but at downstream was as closed boundary and the data was the velocity: U = 0.

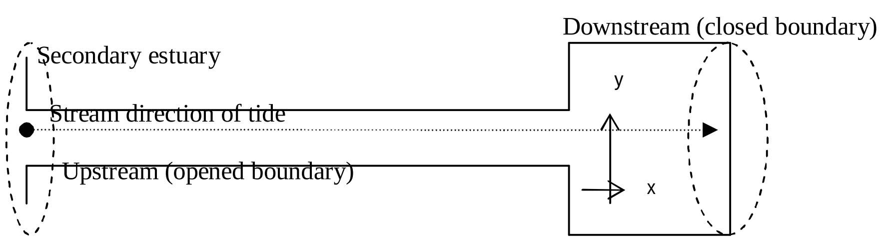

Figure 2 Boundary condition of channel flow with tide pond

Characteristic equation at x positive direction

$$\frac{d}{dt}(U + 2C) = g(Sox - Sfx)$$
$$\frac{\partial x}{\partial t} = U + C$$

Characteristic equation at x negative direction

$$\frac{d}{dt}(U - 2C) = g(Sox - Sfx)$$
$$\frac{\partial x}{\partial t} = U - C$$

Characteristic equation in y positive direction

$$\frac{d}{dt}(V + 2C) = g(Soy - Sfy)$$
$$\frac{\partial y}{\partial t} = V + C$$

Characteristic equation in y negative direction

$$\frac{d}{dt}(V-2C) = g(Soy - Sfy)$$

$$\frac{\partial y}{\partial t} = V - C$$

Note:

U,V = depth-averaged velocity at x and y direction

C = velocity of wave

= $\sqrt{gH}$

Sox = slope based line at x direction

Soy = slope based line at y direction

Sfx = slope energy line at x direction

Sfy = slope energy line at y directions

Shear force

When the wind blew on the surface water, wind with its velocity would generate shear force on the water surface [10], pushed the water mass, and then would create the flow movement. The value of shear force was as follow:

* Shear force at x direction:

$$\tau_{wx} = \lambda\sqrt{U^2 + V^2}\ {*}U$$

* Shear forced at y direction:

$$\tau_{wy} = \lambda\sqrt{U^2 + V^2}\ {*}V$$

Note:

U,V = wind velocity corresponding component at x and y direction

λ = coefficient of drag

Amplitudo of tide

Analysis of tide was based on the assumption that tide was as periodical movement and it was expressed as follow:

$$h_{(t)} = h_o + \sum_{i=1}^{n} h_i \cos\left(\frac{2\pi\ t}{T_t} - \alpha_i\right)$$

Note:

$h_{(t)}$ = water level depth at t

h_o = average of water level depth

h_i = tide amplitudo of i component

T_i = constant of i period (certain and the same for all of the world)

α_i = phase difference of i component

Finite Different Method

The solution of hydrodynamic model was using the equations of continuity and momentum. Then it was solved with numerical method of finite difference. The base principal of two dimensional (2D) finite different was to build 3 functions on the directions of X, Y, and T in cartesian coordinate. Depth value of H, velocity of U, V or discharge of Q could be assumed as the functions of H, U, V, and Q at surrounded points. By using the mthod of explicit finite different, the value of function at a point in time interval of t = (n+1) Δt along coordinate of x or y could be calculated by using the function values of surrounded point at time interval of t = n Δt like calculating of the formula below: (Figure 3 and 4)

$$H_{i,j}^{n+1} F\left(H_{i-1,j}^{n};\ H_{i+1,j}^{n}\ ;\ H_{i,j-1}^{n};\ H_{i,j+1}^{n}\right)$$

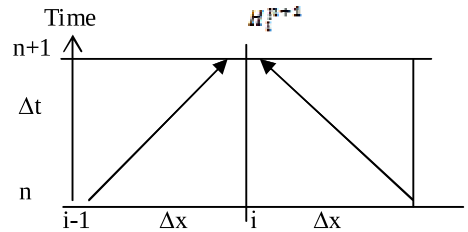

Figure 3 Scheme of explicit finite different (x-coordinate)

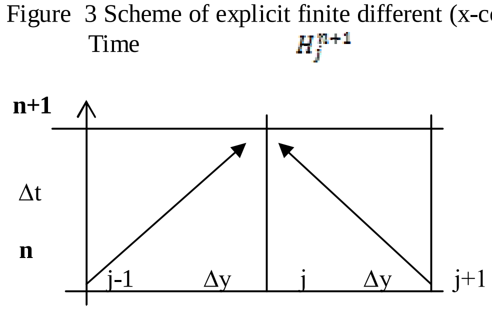

Figure 4 Scheme of explicit finite different (y-coordinate)

Explicit Finite Different of Mac Cormack Method

Continuity and momentum equations would be solved by the scheme of explicit finite different of Mac Cormack and the formula was as follow:

$$\frac{\partial U}{\partial t} + \frac{\partial}{\partial x}(E_x) + \frac{\partial}{\partial y}(F_y) = S$$

$$U = [H, UH, VH]^T$$

$$E_x = \begin{bmatrix} UH \\ UUH - \frac{1}{2} g H^2 \\ UVH \end{bmatrix},$$

$$F_y = \begin{bmatrix} VH \\ UVH \\ VVH \quad \frac{1}{2} g H^2 \end{bmatrix}$$

$$S = \begin{bmatrix} 0 \\ gH(Sox - Sfx) + \frac{\tau_{wx}}{\rho} \\ gH(Soy - Sfy) + \frac{\tau_{wy}}{\rho} \end{bmatrix}$$

Equation solution of algorithm was derived from Mac Cormack predictor-corrector-solution scheme [11] as follow:

At X directions:

Predictor step:

$$\bar{U}_{i,j} = U^n_{i,j} - \frac{\Delta t}{\Delta x} \nabla_x E^n_{i,j} - \frac{\Delta t}{\Delta y} \nabla_y F^n_{i,j} + \Delta t\, S^n_{i,j}$$

Corrector step:

$$\bar{\bar{U}}_{i,j} = \bar{U}_{i,j} - \frac{\Delta t}{\Delta x} \Delta_x \bar{E}_{i,j} - \frac{\Delta t}{\Delta y} \Delta_y \bar{F}_{i,j} + \Delta t\, S^n_{i,j}$$

Solution step:

$$U^{n+1}_{i,j} = 0{,}5\,[U^n_{i,j} + \bar{\bar{U}}_{i,j}]$$

At Y directions:
Predictor step:

$$\bar{V}_{i,j} = V^n_{i,j} - \frac{\Delta t}{\Delta y} \nabla_y E^n_{i,j} - \frac{\Delta t}{\Delta x} \nabla_x F^n_{i,j} + \Delta t\, S^n_{i,j}$$

Corrector step:

$$\bar{\bar{V}}_{i,j} = \bar{V}_{i,j} - \frac{\Delta t}{\Delta y} \Delta_y \bar{E}_{i,j} - \frac{\Delta t}{\Delta x} \Delta_x \bar{F}_{i,j} + \Delta t\, S^n_{i,j}$$

Solution step:

$$V^{n+1}_{i,j} = 0{,}5\left[V^n_{i,j} + \bar{\bar{V}}_{i,j}\right]$$

Note:
$\nabla =$ Backward different eperator, $\Delta =$ forward different operator
$V^{n+1}_{i,j} =$ velocity at y direction point (i,j) at level time t = n +1

RESULTS AND DISCUSSION

Validity of model was evaluated with experimental model that was the evaluation using simulation model of 2D and it was made at a rectangular flow area. Flow movement was built by wind with constant blowing in the diagonal direction of flow area. The simulation result satisfied which produced flow with symetris direction pattern of velocity vector and it could reach steady state (Figure 5) . Evaluation with the input of constant velocity at the estuary of tide pond flow area showed the satisfied result. The result showed thet the pattern of flow line was symetris with velocity and it could reach steady state (Figure 6).

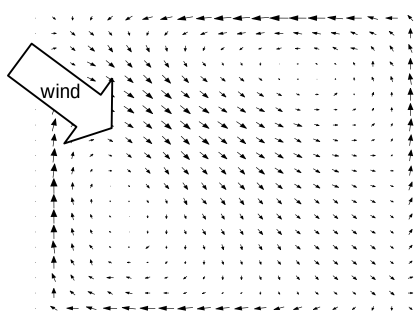

Figure 5 First experiment, flow pattern a

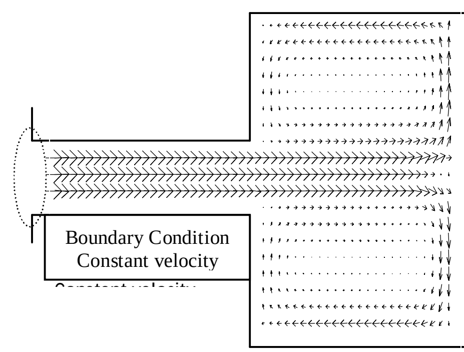

Figure 6 Second experiment, 2-D flow pattern

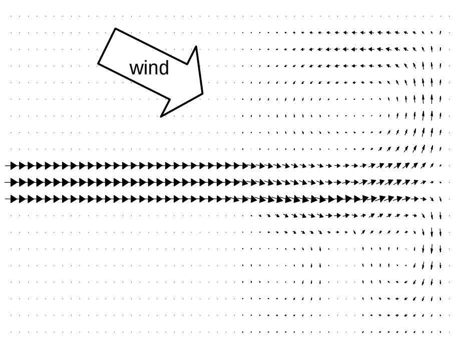

Figure 7 Third experiment, 2-D flow pattern at non symatris tide pond flow area

Evaluation with non symetris shape with the input was tide water and diagonal direction of wind produced flow line pattern was suitable with the prediction of the next flow that was 3 locations of flow turbulence at ebb-tide pond (Figure 7).

Application model on the tidal irrigation

After evaluation of model experiment, the model was tried again with field case that was model simulation of flow area at secondary channel with ebb-tide pond (Figure 8). Field data input of hydraulic parametre was included tide pond of (200 x 250) m^2, the average of depth: H = 2.6 m; amplitudo of ebb-tide was 0.75 m; width of secondary channel was 40 m, coefficient of Manning: n = 0.03; base slope: So = 0.0001; and wind velocity: Va = 10 km/hour. This model simulation was carried out for 4 conditions that were tide water, ebb and wind, position of wind at diagonal, and normal position. These case models were intended to produce the patterns of velocity distribution which was naturally occured at estuary or end channel.

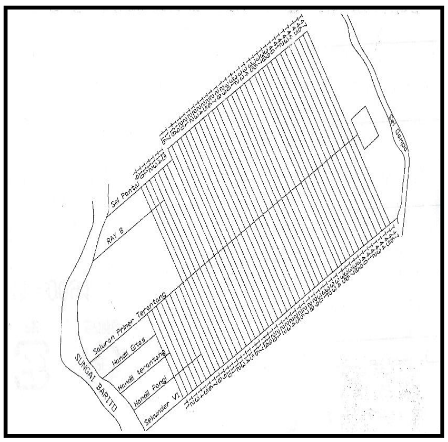

Figure 8 Macro water system of ebb-tide irrigation at Terantang

Model of fied cases were included (1) Flow pattern of ebb-tide water at estuary; (2) Flow pattern of ebb-tide water at pond; and (3) Flow pattern of tide pond and wind effect at pond

Simulation result

(1) Simulation result of first case: flow pattern of ebb-tide water at estuary with input of ebb-tide amplitudo was presented as in Figure 9 and Flow line pattern of ebb water was presented as in Figure 10.

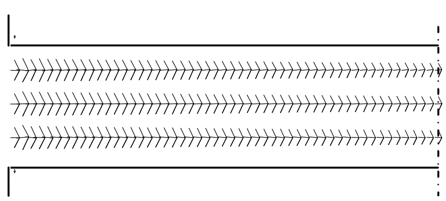

Figure 9 Line movement pattern of tide water flow at secondary estuary: Vmax = 2.40 m/s

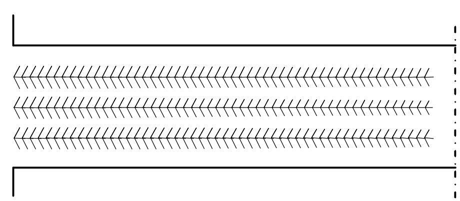

Figure 10 . Line movement pattern of tide water flow at secondary estuary: Vmax = 0.36 m/s

(2) Simulation result of second case: flow pattern of ebb-tide water at end channel (ebb-tide pond) as presented as in Figure 11 and 12.

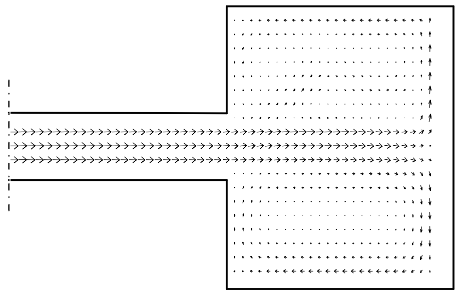

Figure 11 . Line movement pattern of tide water flow at ebb-tide pond: Vmax = 0.40 m/s

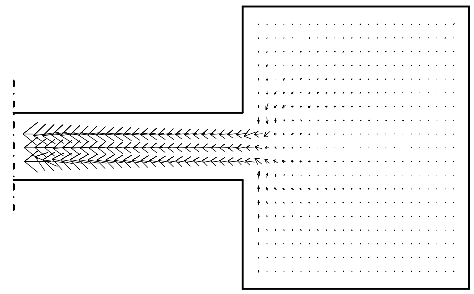

Figure 12 . Line movement pattern of ebb water flow at ebb-tide pond: Vmax = 0.21 m/s

(3) Simulation result of third case: flow pattern of ebb-tide at the end of channel (ebb-tide pond) with wind effect as presented as in Figure 13 and 154 below.

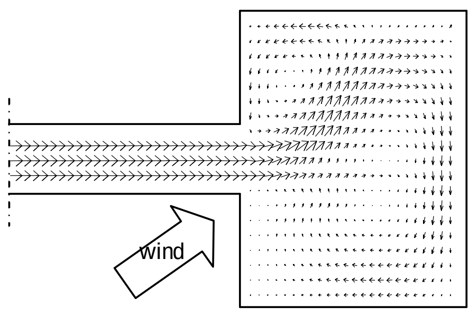

Figure 13 Line movement pattern of tide water and wind-1 at ebb-tide pond: Vmax = 0.31 m/s .

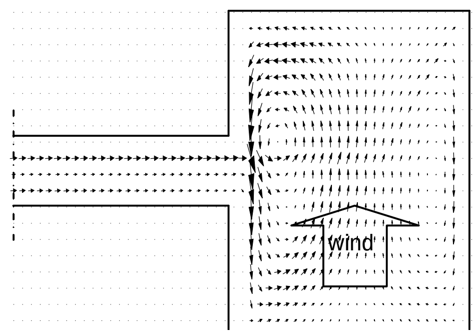

Figure 14 Line movement pattern of tide water and wind-2 at ebb-tide pond: Vmax = 0.46 m/s .

Based on the above result , it could be presented a changed trend of velocity fluctuation at the whole channel section when ebb and tide with different condition. Proses of ebb water with phenomena of flow water movement in down direction with gravitation energy. It began from the end of channel, part of flow water movement crashing left or right side of the wall and reflected back to center became the flow resultant from right and left side and simoultanously occuring at center line of channel so that flow at center line was bigger than left and right line.

On the other hand, phenomena of tide water with tide wave energy showed that part of energy which spreaded at right or left side of channel wall was refelected back to center line of channel, while reflected flow got obstacle from ebb water mass which was caught in front of them with water mass being concentrated in center line so that tide flow movement turned back to the edge direction at right and left side and then continously moved to flow. The result of this was velocity at right or left line of channel was bigger than at the center one. Ebb water mass which was caught, could be pushed back by tide water mass, then it was slowly moved back in the same direction with tide water so that velocity at center line was relative small. Monitoring result of 24 hours, velocity trend was presented as in Figure 15 and 16.

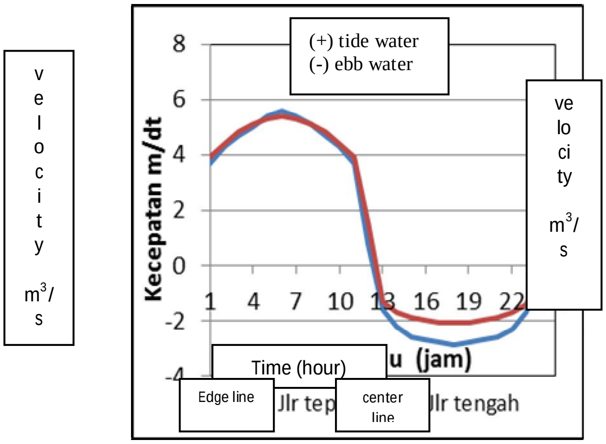

Figure 15 Graphic of ebb-tide water

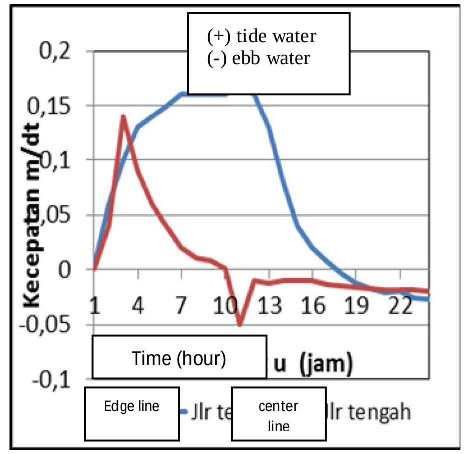

Figure 16 Graphic of ebb-tide water velocity

CONCLUSION

Based on the results of simulation and hydrodynamic model, it was concluded as follow. Result of hydrodynamic model and phenomena of ebb-tide water at prototype, there was similarity of flow movement line pattern with non significant difference. Generally, flow velocity of tide water was bigger than ebb one. Flow velocity of ebb and tide at the whole section was in variety. Tide water velocity at center line was smaller than at right or left side. On the other hand, velocity at center line was bigger that at rigjt and left side. Model simulation of hydrodynamic with input alternative of constant velocity with symetris shape could produce symetris flow line pattern with steady velocity. Simulation with input of wind blowing could produce flow line pattern with line movement followed the direction of wind blowing. Flow velocity characteristic of tide and ebb water at estuary and the end of channel was not the same. Water movement of tide and ebb water at estuary of center line and edge was moving with the same time but the flow velocity was different. Characteristic at the end of channel, the movement of tide and ebb water at center line and edge showed that there was the difference time and flow direction. The movement of tide water at edge line was later than at the center, but there was faster at edge line for ebb water. Therefore, duration of edge line was later than center line at the end of channel for 1 period (1 day) of ebb tide. Flow pattern and velocity would be able to predict the pattern of sediment transport and the otger pollutant.

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