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Sediment Transport Study In Estuary Of Weriagar River, Kabupaten Teluk Bintuni, West Papua

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ABSTRACT

Sediment transport study can be done by 3D numerical modeling for hydrodynamic and sediment transport simulation. In this study, 3D numerical modeling is calibrated by observation data, such as surface elevation and current speed. Hydrodynamic and sediment transport in estuary of Weriagar River is simulated for 31 days. Hydrodynamic simulation result shows that hydrodynamic in Weriagar River is dominated by river discharge while tide dominates the hydrodynamic in the estuary. Current speed is increasing during spring tide but current flows faster during ebb because the river discharge also flows to the estuary. Vertical profile indicates that current speed decreases as the elevation gets deeper. This condition is caused by bed resistance near the bed. Sediment transport simulation result shows bed level changes in Weriagar River. Maximum erosion occurs about 20 cm near the river bend with bed level change rate 0,02 m/day. Maximum erosion occurs in this location because the flow pattern and current speed increases at ebb condition. At the estuary, the erosion occurs with small intensity. This happens because longshore current from sea is entering the river mouth but is blocked by more dominate river discharge. Current speed affects suspended sediment concentration and bed level change rate.

Keywords: *erosion, hydrodynamic, sediment transport (11 pt)*

ABSTRAK

Studi transportasi sedimen dapat dilakukan dengan pemodelan numerik 3D yaitu dengan melakukan simulasi model hidrodinamika dan transportasi sedimen. Pemodelan numerik 3D pada studi ini dikalibrasi menggunakan data hasil pengamatan, yaitu elevasi muka air dan kecepatan arus. Simulasi hidrodinamika dan transportasi sedimen di muara Sungai Weriagar dilakukan dengan durasi selama 31 hari. Hasil simulasi hidrodinamika menunjukkan bahwa pola hidrodinamika di wilayah badan Sungai Weriagar didominasi oleh pengaruh debit sungai, sedangkan di wilayah muara sungai lebih didominasi oleh pasang surut. Pada kondisi purnama kecepatan arus di Sungai Weriagar meningkat, namun pada saat surut kecepatan arus lebih besar dibanding saat pasang dikarenakan pengaruh debit sungai yang mengalir ke muara. Dari profil potongan vertikal, kecepatan arus menurun seiring bertambahnya kedalaman. Hal ini dikarenakan adanya pengaruh bed resistance di dekat dasar perairan. Hasil simulasi transportasi sedimen menunjukkan bahwa terjadi perubahan elevasi dasar perairan di Sungai Weriagar. Erosi maksimum terjadi sebesar 20 cm yaitu di lokasi sekitar belokan sungai, dengan laju perubahan dasar perairan 0,02 m/hari. Lokasi ini mengalami erosi maksimum akibat pola arus di dalam sungai, khususnya pada kondisi surut dimana kecepatan arus meningkat. Di pesisir muara sungai juka terindikasi erosi namun intensitasnya lebih kecil. Di bagian ini erosi disebabkan arus sejajar pantai dari laut yang akan masuk ke sungai saat kondisi pasang, namun tertahan oleh debit sungai yang cenderung lebih dominan di badan sungai. Kecepatan arus mempengaruhi perubahan konsentrasi TSS dan laju perubahan dasar perairan di lokasi.

Kata kunci: *erosi, hidrodinamika, transportasi sedimen*

1. INTRODUCTION

Estuary is a transition zone where river meets the ocean. Morphology of an estuary depends on sediment transport occurred, which is directly affected by physical processes that take place in the river and in the ocean, such as river flow, tide and tidal current [1], [2]. In West Papua Province, there are many rivers flow across the region. Weriagar River is one of the river in the region that flows towards Bintuni Bay with length about 74 km, width varies between 100 m to 197 m and depth between 3 m and 7 m.

Data from airborne or space sensors are important source of information for monitoring coastal processes [3]. From Google Earth image, there are 3 main eroded areas detected in this location: (a) high intensity erosion at riverbank where a lot of houses located; (b) medium intensity erosion at riverbank with open spaces and few houses; (c) low intensity erosion at riverbank with open spaces (Figure 1). This study is conducted to understand sediment transport process occurred in the area.

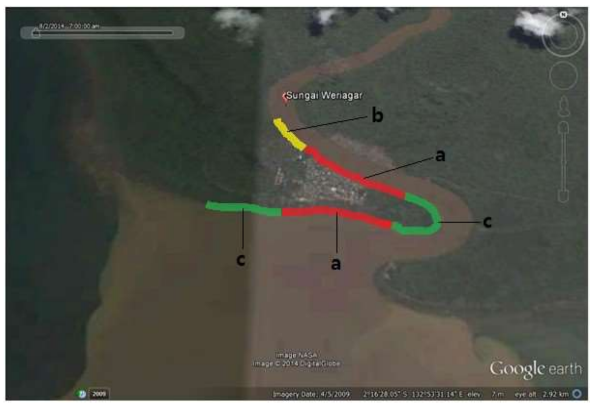

Figure 1. Erosion Detected at Weriagar Riverbank (a) High intensity erosion, (b) Medium intensity erosion, (c) Low intensity erosion [3]

2. METHODOLOGY

In this study numerical modelling is used to simulate the complex process of sediment transport in estuary. 3D numerical modelling is used in this study which consists of 2 main parts: hydrodynamic simulation using Hydrodynamic Module (HD) and sediment transport simulation using Sand Transport Module (ST). In the early stage, mesh construction based on flexible mesh is done using bathymetry data from secondary data collection. Structurized mesh is used on vertical domain based on sigma coordinate transformation to get identical topology of each layer of the mesh model. While for the horizontal domain, unstructurized mesh is used. 5 boundary conditions are defined on the model with 1 land boundary, 3 ocean boundaries and 1 river boundary. Surface elevation data based on global tide model is used for the ocean boundaries. Because of the unavailability of existing discharge value of the river, the discharge value for the boundary will be extracted after calibration of the hydrodynamic simulation. Horizontal mesh and boundary conditions used in the model shown in Figure 2.

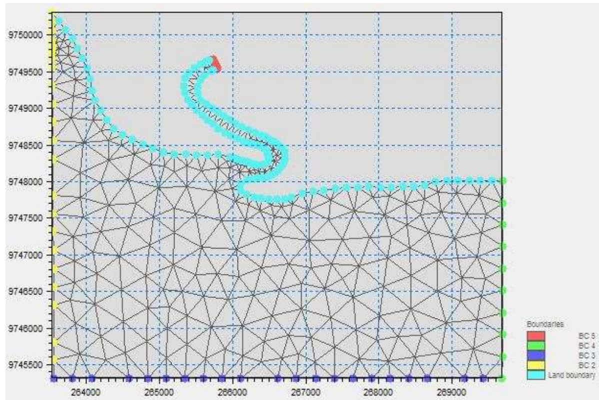

Figure 2. Horizontal Mesh and Boundary Conditions

Modelling the whole process of sediment transportation is conducted with flexible mesh couple model of both hydrodynamic and sand transport module. Output of the model which will be used to analyze the sediment transport at the location are surface elevation, current speed and direction, sediment transport pattern and sediment concentration. Analysis of model output will be conducted to describe sediment transport process occurring at the estuary of Weriagar River. The complete procedure of this study can be seen in Figure 3.

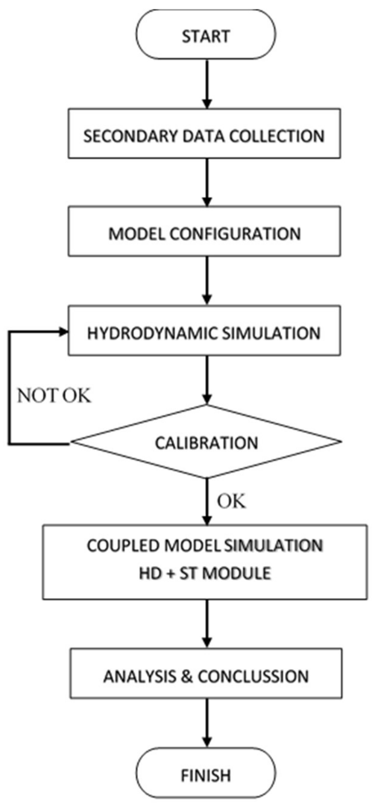

Figure 3. Simulation Flowchart

3. RESULT AND DISCUSSION

3.1 Calibration and Verification

Calibration is needed to make sure the model could produce result that close to real environment. In this study the parameter calibrated are river discharge and roughness height. Surface elevation and current speed resulted from the simulation will be compared with field data. Model evaluation is done by calculating normalized root mean square error (N-RMSE) using equation shown in (1).

$$N - RMSE = \frac{\sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{N}}}{x_{max} - x_{min}} \times 100\% \quad (1)$$

where x is the field data, $\hat{x}$ is model data and N is number of data being compared. Calibration in this study is conducted with assumption that surface elevation and current speed contributes 45% and 55% each to the total percentage of RMSE.

Total percentage of RMSE for each combination of discharge value and roughness height is shown in Table 1Error! Reference source not found.. The minimum value of the total RMSE percentage is 20.79% with discharge value is 100 m^3/s and roughness height is 0.1 m. For verification purpose, these values are used to compare tidal constituent resulted from the model with field data. Blumberg, et. al, [5] recommend that RMSE of the amplitude for most dominant tidal constituent should be about 10 cm. The most dominant tidal constituent in the study area is M2 constituent, where the RMSE between the model and field data is about 2.82 cm (Table 2). RMSE for the tidal height between the model and the field data is 0.5 m. From these values we can assume that the model has given a representative simulation result compared to field data.

Table 1. Calibration Result

Discharge (m^3/s)	Roughness Height (m)	%RMSE					Total %RMSE
		Surface Elevation	Current Speed				
		P5	P1	P2	P3	P4	
25	0.075	13.6	45.7	26.8	40.1	39.4	27.01
	0.1	13.4	45.8	26.8	40.2	39.7	26.98
	0.2	13.3	46.1	26.8	40.3	40.0	27.05
	0.3	13.2	46.3	26.9	40.4	40.2	27.08
50	0.075	13.6	37.4	24.3	36.1	36.8	24.63
	0.1	13.4	37.5	24.3	36.2	37.1	24.61
	0.2	13.3	38.0	23.5	36.5	37.5	24.75
	0.3	13.2	38.4	24.6	36.6	37.8	24.83
100	0.075	13.9	26.6	20.0	28.3	30.7	20.82
	0.1	13.8	26.8	20.1	28.4	31.0	20.79
	0.2	13.9	27.4	20.3	28.8	31.6	21.13
	0.3	14.0	27.8	20.5	29.1	31.9	21.35
200	0.075	16.8	38.4	15.2	20.8	22.0	20.81
	0.1	16.9	38.1	15.3	20.9	22.2	20.88
	0.2	17.8	36.7	15.5	21.1	22.8	21.23
	0.3	18.5	35.7	15.7	21.2	23.1	21.51

Table 2. Tidal Constituents of Field Data and Model

Tidal Constituent	Field Data		Model		RMSE	
	Amplitude (cm)	ϕ (°)	Amplitude (cm)	ϕ (°)	Amplitude (cm)	ϕ (°)
M2	68.82	5.55	66	32.75	2.82	24.8
S2	23.57	13.06	14	200.25	9.57	187.19
K1	31.72	248.88	13	206.65	18.72	40.23
O1	20.26	-87.52	9	-17.14	11.26	65.38

3.2 Hydrodynamics Component

Hydrodynamic results are observed at 9 points shown in Figure 4 which 1 point (P5) is tidal observation point, 4 points (P1, P2, P3, P4) are current observation points and 4 pre-defined points (P6, P7, P8, P9) scattered throughout the estuaries. These points are chosen in restropect of its distance to the actual tidal and current observation points also the area where the effect of interchanging between river and sea would occur [6].

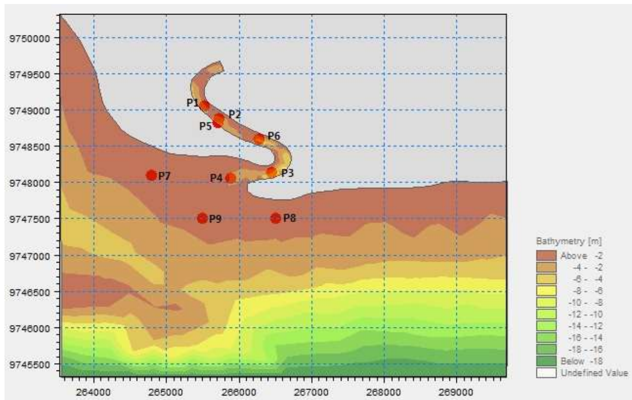

Figure 4. Observation Points

During ebb, the surface elevation at P1 to P6 are about -0.7 m while at P7 to P9 are about -1.5 m. These indicate that P1 to P6 which are located at the river channel, are more affected by river discharge rather than P7 to P9 which are located outside the river channel. As shown in Figure 5 we compare tidal heights at P1 and P7. It shows that the further an observation point from the river discharge source, the tidal height will become higher.

Current speeds from the simulation at the 9 observation points shows varying characteristics. Current speeds at P1 and P7 to P9 are greater than at P2 to P6. P1 is located the nearest from the river discharge source so the current speed is affected more by the river discharge while P7 to P9 are located outside the river channel so the current speeds are affected by the wave current. On the other hand, P2 to P6 are located throughout the river channel but not near enough from the river discharge source so the current speeds are slower. Comparison of current speed at P1, P6 and P9 are shown in Figure 6.

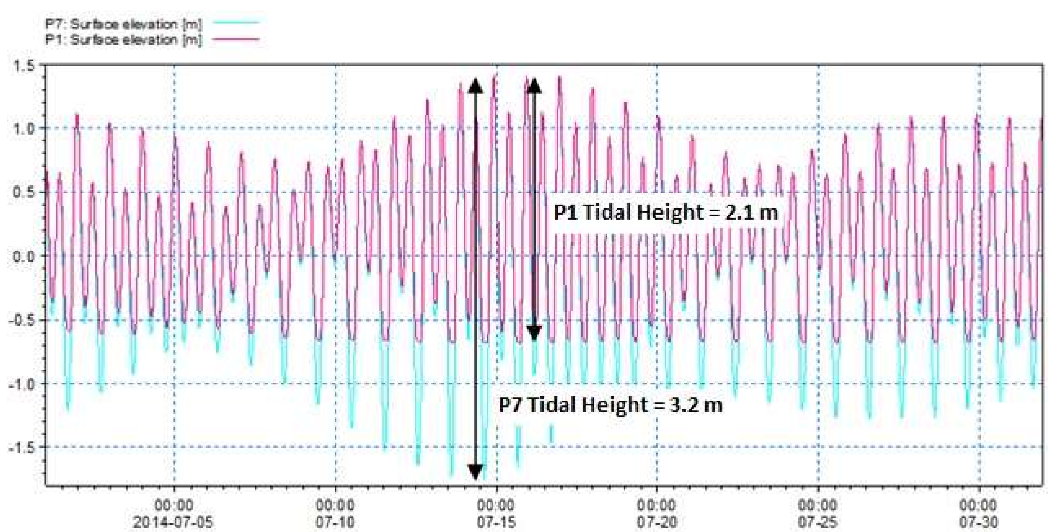

Figure 5. Tidal Height at P1 (located at river channel) and P7 (located outside river channel)

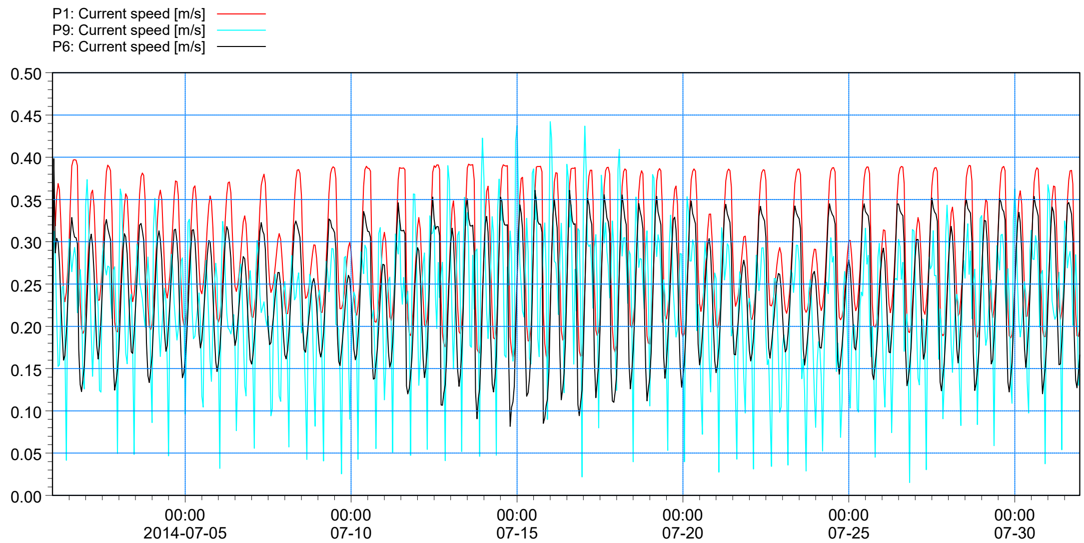

Figure 6. Current Speeds at P1 (located nearest from river discharge source), P6 (located at river channel) and P9 (located outside the river channel)

Current flow in the river channel is dominated by the effect of river discharge meanwhile at the estuary is dominated by tides (Figure 7). In the river channel, current always flows downstream to the estuary. Outside the river channel or at the estuary, current flows accordingly depend on the tidal condition whether it is currently flooding or ebbing.

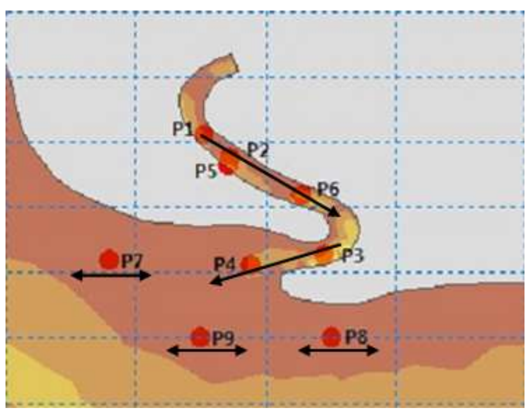

Figure 7. Current Flows at the Observation Points

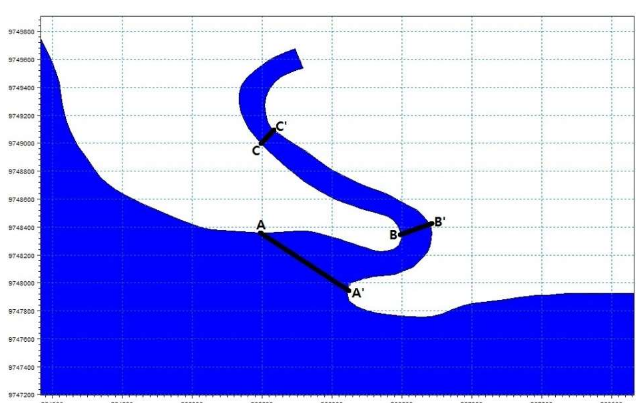

Figure 8. Locations of Vertical Plane to Inspect Current Speed Profile along the Water Depth

Current speed profile along the water depth could be explained by inspecting the vertical plane of the water depth. In this study 3 sections are inspected, which is A-A', B-B' and C-C' (Figure 8). From the vertical plane of these 3 sections is indicated that current speed during the ebb tide is greater than during the flood tide. This condition is mainly caused by the effect of river discharge flows downstream to the estuary. Current speed near the seabed is much lower because it is affected by the bed resistance. From the 3 sections inspected, section C-C' which is located in the river channel has higher current speed than section A-A' which is located at the estuary. Current speed profile for each section are shown in Figure 9 to Figure 11.

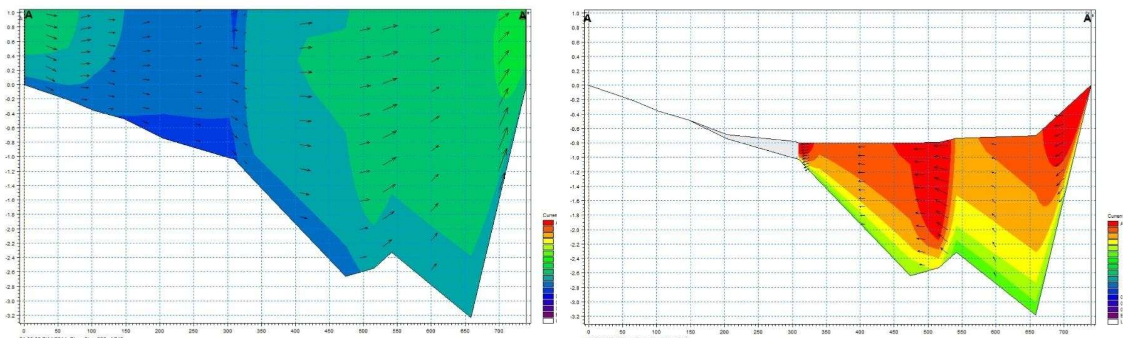

Figure 9. Current Speed Profiles at A-A' Vertical Section during Flood and Ebb Tide

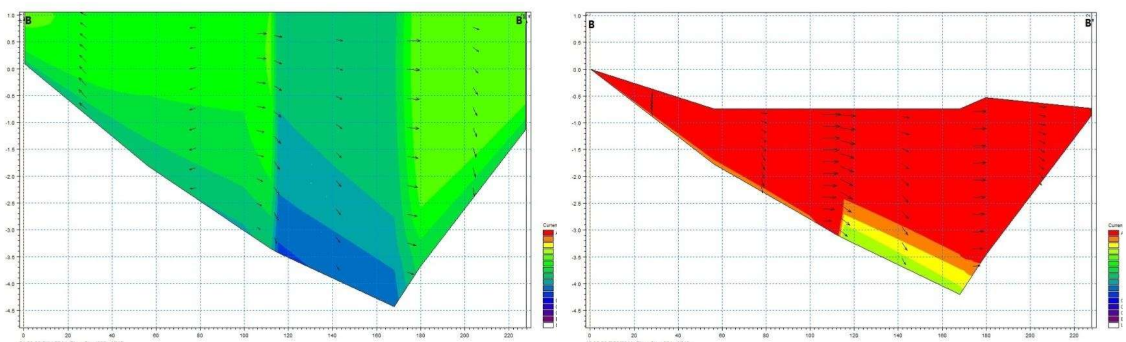

Figure 10. Current Speed Profiles at B-B' Vertical Section during Flood and Ebb Tide

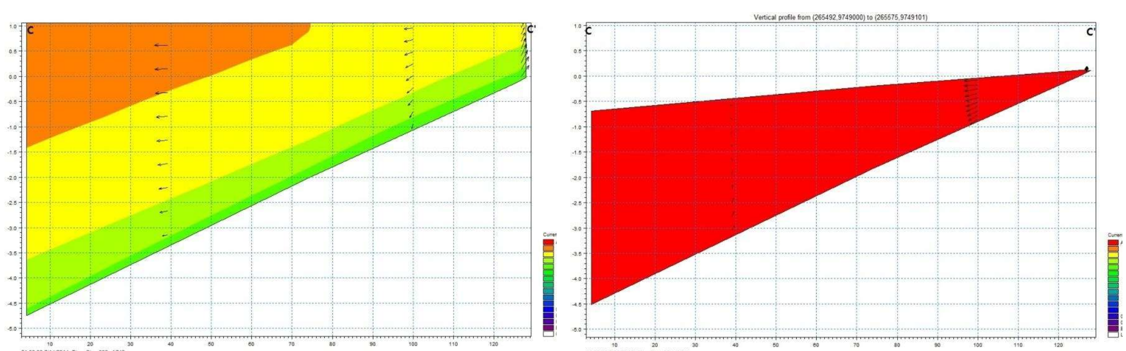

Figure 11. Current Speed Profiles at C-C' Vertical Section during Flood and Ebb Tide

3.3 Sediment Transport Component

The results from sediment transport simulations are suspended sediment concentration and bed level which are depth-averaged values. From the simulation it is indicated there are few areas experiencing bed level changes. As shown in Figure 12 yellow and red areas are where erotion occurred while green areas are where sedimentation occurred. Maximum erotion occurred at the river bends with 20 cm erosion at the rate 0,02 m bed eroded per day. This condition is caused by the current flow pattern in the river channel, especially during the ebb tide where the current speed is increasing. Outside the river channel or estuary, the coastline is also eroded but with less intensity. In this area, erotion is caused by longshore current from the sea which will enter the river during the flood tide but is blocked by the more dominant river discharge in the channel.

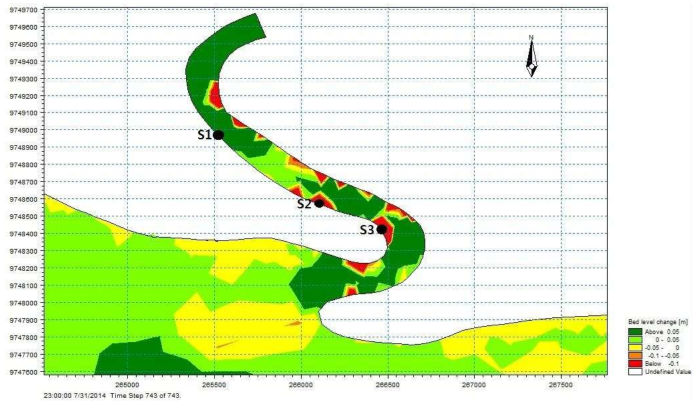

Figure 12. Bed Level Changes during the Simulation Period

In Figure 12 we inspected 3 locations which are 1 sedimented location (S1) and 2 eroded locations (S2 and S3). By comparing the suspended sediment concentration in these locations with the current speed we can conclude that the greater the current speed then seabed will erode so sediment particle which eroded will float along the water depth, resulted in the increase of suspended sediment concentration. Suspended sediment concentration at S3 is nearly zero because it is located at the river bend facing directly the open sea where river discharge has little effect on it. Figure 13 to Figure 15 shows suspended sediment concentration graph compared with the current speed at the 3 locations. Suspended sediment concentration at the end of simulation period is shown in Figure 16 which shows that suspended sediment concentration is distributed evenly from the upstream till the river bend in front of the estuary. At the areas after the river bend to the estuary, suspended sediment concentration is no longer affected by the river discharge.

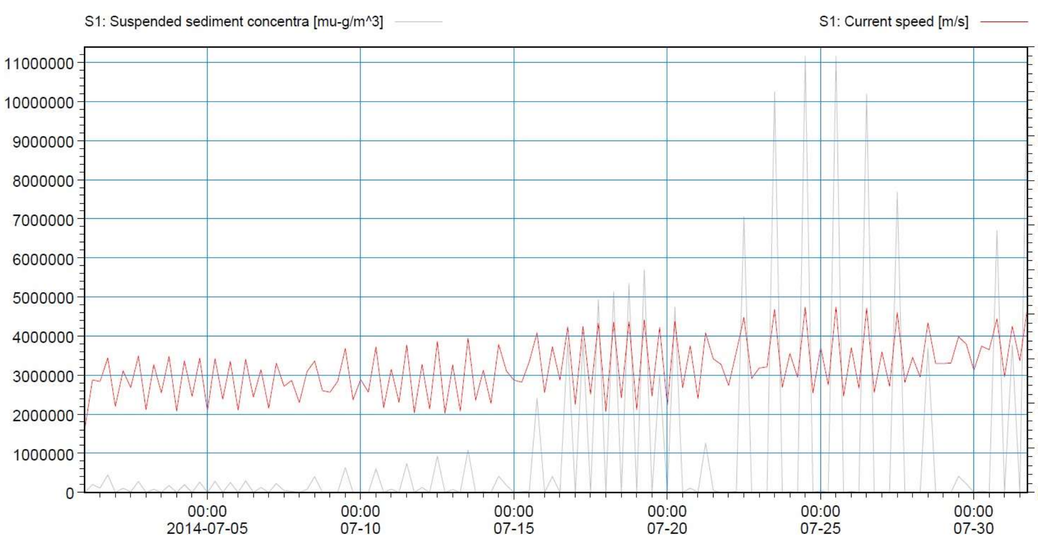

Figure 13 Suspended Sediment Concentration vs Current Speed at S1

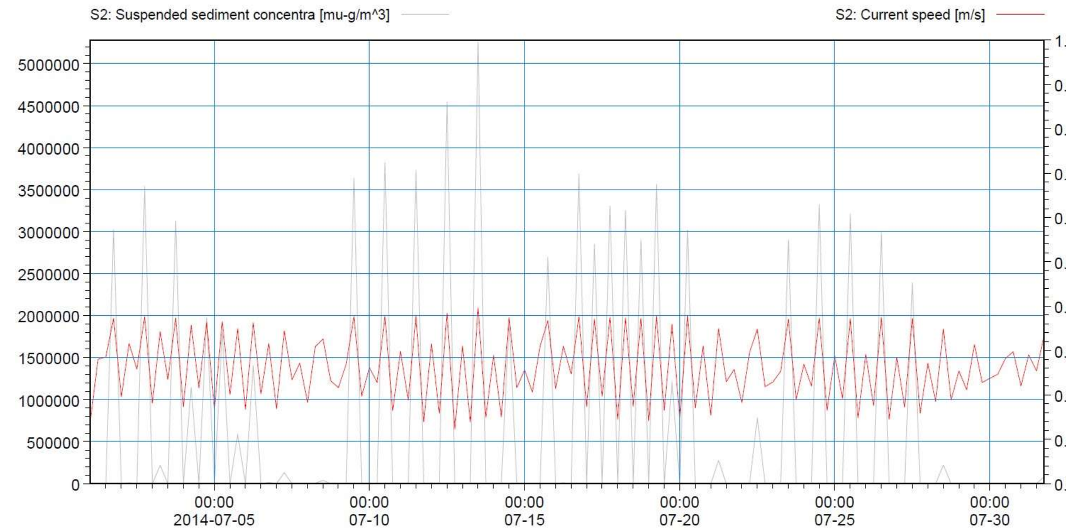

Figure 14. Suspended Sediment Concentration vs Current Speed at S2

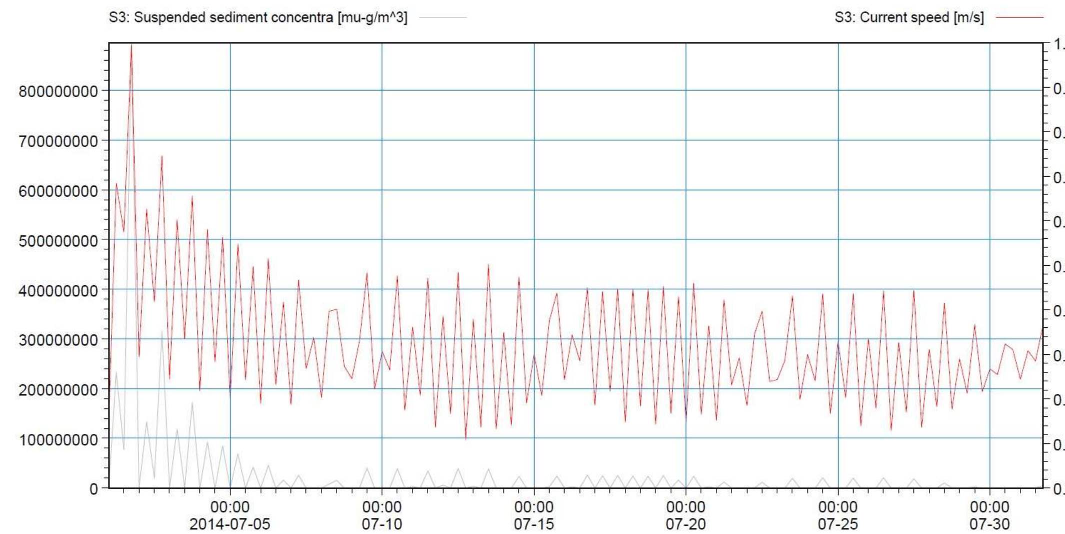

Figure 15. Suspended Sediment Concentration vs Current Speed at S3

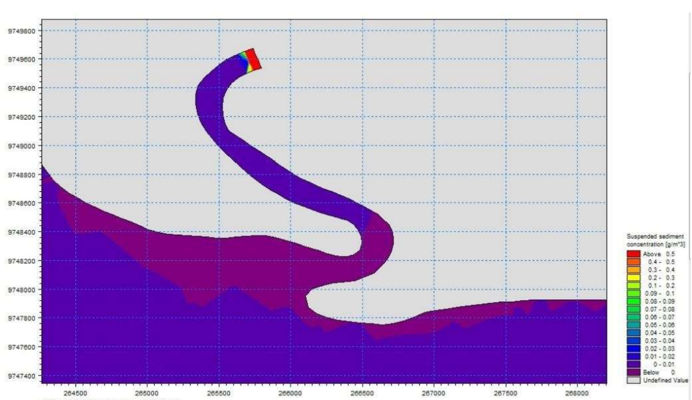

Figure 16. Suspended Sediment Concentration at the end of Simulation Period

4. CONCLUSSIONS

Hydrodynamic characteristic in the study area is dominated by river discharge and tidal. In the river channel, river discharge is more dominant meanwhile at the estuary the most dominant force is tides. Current flows downstream in the river into the estuary but at the estuary the flow is affected by the longshore current of the wave. From the vertical section of the current profiles, it is indicated that depth affected the current speed. Current speed near the seabed is lower because the effect of bed resistance.

During the 31 days simulation period, maximum erotion occurred at the river bend near the estuary with bed level change about 20 cm. Less intense erotion also occurred at the estuary coastline but this is more affected by the tides rather than the river discharge. Suspended sediment concentration and the bed level changes in the study area are affected by the current speed.

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