Analysis of Erosion and Sedimentation Patterns Using Software of Mike 21 HDFM-MT in The Kapuas Murung River Mouth Central Kalimantan Province

Analisis Pola Erosi dan Sedimentasi Menggunakan Software Mike 21 HDFM-MT di Muara Sungai Kapuas Murung Propinsi Kalimantan Tengah

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ABSTRACT: The public transportation system along the Kapuas River, Central Kalimantan are highly depend on water transportation. Natural condition gives high distribution to the smoothness of the vessel traffic along the Kapuas Murung River. The local government has planned to build specific port for stock pile at the Batanjung which would face with natural phenomena of sedimentation and erosion at a river mouth. Erosion and sedimentation could be predicted not only by field observing but it is also needed hypotheses using software analysis. Hydrodynamics and transport sediment models by Mike 21 HDFM-MT software will be applied to describe the position of sedimentations and erosions at a river mouth. Model is assumed by two different river conditions, wet and dry seasons. Based on two types of conditions the model would also describe the river flow and sediment transport at spring and neap periods.

Tidal fluctuations and a river current as field observation data would be verified with the result of model simulations. Based on field observation and simulation results could be known the verification of tidal has an 89.74% correlation while the river current correlation has 43.6%. Moreover, based on the simulation the sediment patterns in flood period have a larger area than ebb period. Furthermore, the erosion patterns dominantly occur during wet and dry season within ebb period. Water depths and sediment patterns should be considered by the vessels that will use the navigation channel at a river mouth.

Keywords: Kapuas Murung River, software Mike 21 HDFM-MT, erosion and sedimentation pattern

ABSTRAK: *Penduduk yang berada di sepanjang Sungai Kapuas sangat bergantung pada transportasi air. Kelancaran lalu lintas kapal di sepanjang Sungai Kapuas Murung sangat tergantung dengan kondisi alam yang terjadi. Rencana pemerintah daerah yang akan membangun pelabuhan khusus batubara di Batanjung akan berhadapan dengan fenomena alam yang umum terjadi di muara sungai yaitu sedimentasi dan erosi.*

Prediksi akan terjadinya sedimentasi dan erosi tidak hanya ditunjang pengamatan lapangan namun juga perlu dilakukan dengan melakukan hipotesa menggunakan bantuan analisis software. Penelitian ini akan menggambarkan posisi sedimentasi dan erosi di sekitar muara dengan pemodelan hidrodinamika dan transport sedimen yang menggunakan Software MIKE 21 HDFM-MT. Model dibuat dengan mengasumsikan kondisi sungai pada saat musim hujan dan musim kemarau. Berdasarkan dua kondisi tersebut model akan menggambarkan sebaran arus dan sebaran sedimen untuk periode bulan baru dan perbani.

Data lapangan pasang surut dan kecepatan arus akan diverifikasi ke hasil simulasi model. Berdasarkan data hasil pengukuran lapangan dan data hasil simulasi model maka dapat diketahui bahwa verifikasi nilai pasang surut menunjukkan korelasi sebesar 89.74% sedangkan verifikasi nilai arus sebesar 43.6%. Selanjutnya dari hasil simulasi didapatkan bahwa pada saat pasang, gambaran posisi sedimentasi banyak terdapat pada bagian timur muara sungai dengan penyebaran cukup luas sedangkan pada kondisi surut area lebih sedikit. Selanjutnya gambaran daerah yang tererosi banyak terjadi pada saat air surut baik untuk musim hujan maupun kemarau. Kapal yang akan menggunakan muara sebagai alur pelayaran harus mempertimbangkan kondisi kedalaman air yang ada dan juga pola sedimentasi yang terjadi.

Kata kunci*: Sungai Kapuas Murung, software Mike 21FM HD-MT, erosi dan pola sedimentasi*

INTRODUCTION

The Kapuas River has about 600 km in length. This river is a main river in Kapuas Regency Central Kalimantan Province. It includes as Integrated Economical Management Region among catchment areas of Kayahan, Kapuas and Barito River (KAPET DAS KAKAB). The Kapuas River has a lot tributaries, one of them is Kapuas Murung River which situated in southern part of Central Kalimantan Province. The upstream of Kapuas River has a lot of mines and another valuable material. Since land transportation is inadequate to transport mining from mine site to another places therefore water transportation has been chosen as modes of transportation. Among those three rivers, the Barito River has preferred as transport the mining. It caused of the infrastructures in this river is better than other rivers. In term of increasing the revenue of local government especially of Central Kalimantan Province, hence they have planned to build the railroad from the Puruk Cahu in upstream to the Batanjung in downstream near the river mouth of Kapuas Murung River.

The Batanjung is located inside the river mouth of Kapuas Murung River that planned to be a port for the coal stock pile, (Dishub Kapuas, 2008). The coal from the Batanjung will be transported by barges to a mother vessel in the offshore. For that reason, the understanding of erosion and sedimentation around the river mouth must be recognized to achieve a secure transport and to obtain the impression of the characteristic of the area.

Normally, the hydrodynamic river mouth is affected not only from river discharge but also a coastal dynamic. Common problem in the river mouth are erosion and deposition where hydrodynamic activity and sediment transport give major influences in term of erosion and sedimentation phenomena. That problem could be hamper water transportation in particular of vessel traffic in the river mouth. As a consequence, water depth information along a ship track is very important to be provided. In addition, a ship track selection must be completed by taking into account the potentially areas of erosion and sedimentation especially in particular circumstances.

Hydrodynamics and mud transport models have been completed to determine the pattern of erosion and deposition around the river mouth of Kapuas Murung River. The model would present the erosion and

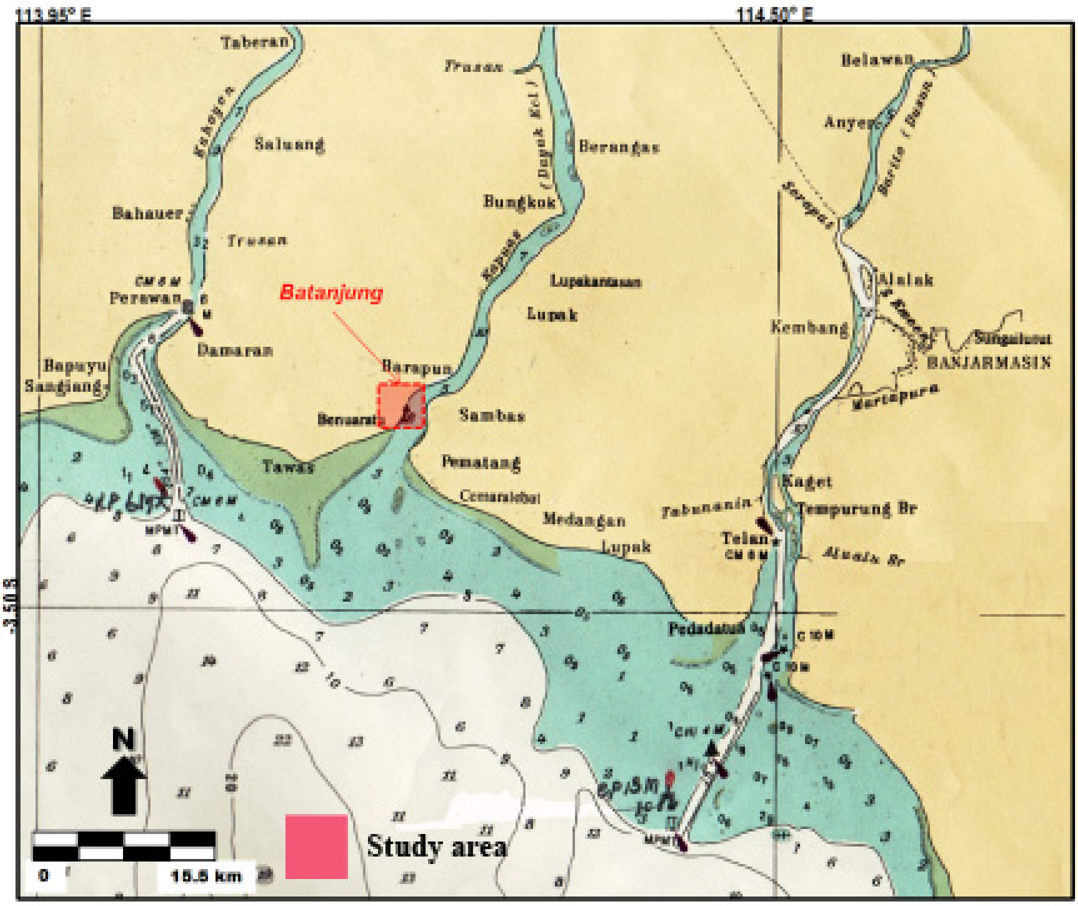

Figure 1. The Map Number of 150, Dishidros TNI-AL

sedimentation pattern in two different scenarios where models completed in wet and dry seasons. As a result, the understanding of the erosion and sediment pattern in the river mouth of Kapuas Murung River could be used to select the ship track of mine transport in the Kapuas Murung River.

The best result would be achieved not only by applying a good model but also by an understanding the real condition of the study area. The conditions of the area such as water depth, tidal fluctuation, hydrology, geology, current speed and current direction are important factors to simulate the hydrodynamic and mud transport model around the river mouth. More completed illustration of the parameters would be described below.

Based on the Map Number of 150, Dishidros TNI-AL, it could be seen that the Kapuas Regency has a ±18.9 km coastal zone where the river mouth of Kapuas Murung River does not have inlet channel (Figure 2).

The recent survey is conducted by Priohandono et.al, (2010) that illustrates the condition of the river mouth as the area which is contained in various water depths. As we can see in the Figure 2 where the red color represents 0 – 1 meters water depth which almost covered the whole area of a river mouth. The deepest area around the river mouth could be found near the Batanjung where the deepest of a water depth reaches more than 8 meters. In addition, the southern part of the offshore could be found as offshore region with approximately water depth 3-8 meters.

A tidal fluctuation based on the measure by (Priohandono, 2010) could be seen in the Figure 3 which illustrates the mean sea level is 174.1 cm. Tidal components such as M2, S2, K1, O1 have an amplitudes 32.3, 3.6, 80.8, 37.7 cm respectively. The spring condition in dry season occurs at 24 of July 2010 and the neap condition occurs at 1 of August 2010. The formzal number is 2.148 that means the tidal is classified as mix mainly diurnal.

The water flow at the river mouth is dominated by tidal effect that shows the flood current direction has an opposite direction when the ebb. The flood current presents the flow direction comes from offshore to the river. Based on 25 hours river flow observation, the current maximum reaches more than 2.43 knot (Priohandono, et al, 2010).

The catchment area of the Kapuas River could not be found that might be caused by among Kahayan River, Kapuas River and Barito River are connected . However, the length of Kapuas River could be calculated as ±600 km and Kapuas Murung River has ±66.38 km.

Based on geological map number 1713-Amuntai and 1712-Banjarmasin, cited from (Sikumbang, 1994) Figure 4 it can be seen that the area of interest is covered by the Qa that means alluvial. The alluvial consists of silt, clay, swamp and sand-gravel. The alluvial deposit is underlain by Dahor Formation which is characterized by siltstone, conglomerates, claystone, lignite and limonite. Below Dahor Formation it is Warokin Formation which is consists of sandstone, claystone and coal. The lowermost layer of this area is dominated by Tanjung Formation which is characterized by sandstone, claystone and limestone

The recent study about the estuary condition is completed by (Dalrymple, 2007). He describes the estuary circumstance as two main conditions. The first condition is a tide dominated estuary and the second is tide dominated delta.

As can see in Figure 5a, it describes the schematic map of a tide-dominated estuary where the outer margin of mudflats is commonly bordered by an erosional channel margin, (Dalrymple, 1992). At longitudinal variation of salinity through a tide-dominated estuary the shaded zone is an indication of the temporal variability of salinity that occurs because of changes in the river discharge where the salinity gradient migrates up estuary as the river discharge decrease and down estuary when the river discharge is higher, (Dalrymple, 2007).

In addition, Figure 5b describes illustrates the schematic map of tide-dominated delta where it based by loosely on the Fly River delta, Papua New Guinea. The influence of the river is greater than tidal currents and waves so the bed load of the convergence (BLC) is hypothesized to occur in the distributary-mouth-bar area, (Dalrymple, 2003).

A sediment transport capacity of the hydraulic system which reduced due to the decrease of the steady current and oscillatory wave flow velocities and related turbulent motions that usually would be a place of the sedimentation, (Van Rijn, 2004). As can be seen in Figure 6, the manmade structures are used to manage the problem at the estuary. The most important of the water transportation at the river mouth is for the navigation channel which should be used by vessel to go to upstream. Solving the problem in the river mouth must consider not only building the structure but the important is to understand the circulation of the sediment around the area.

METHODS

The flexible mesh is generated by using the mesh generator which creates detailed digital mesh for use in the MIKE Zero flexible mesh (FM). Within two-dimensional model the elements would be considered as triangles and quadrilateral elements. The mesh file that yielded by mesh generator is an ASCII file which includes information of the geographical position and water depth at each node point in the mesh, (DHI,

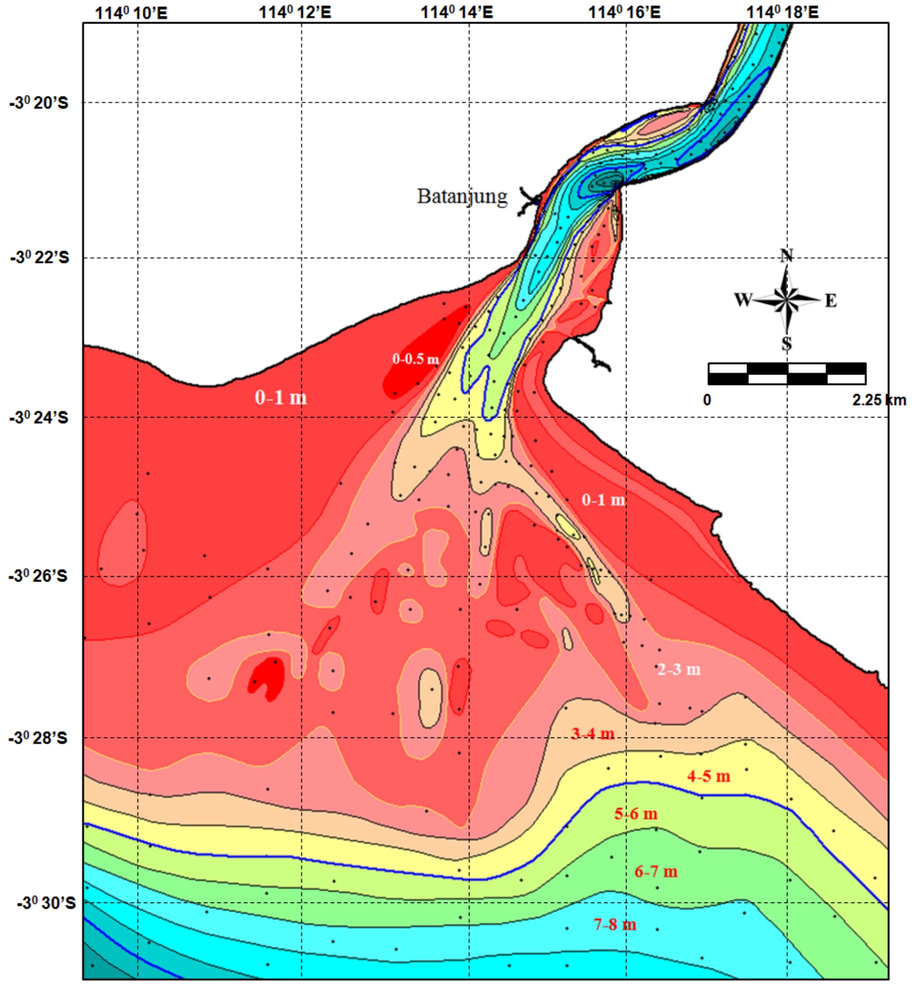

Figure 2. Bathymetry around the River Mouth of the Kapuas Murung River, (Priohandono, et. al, 2010)

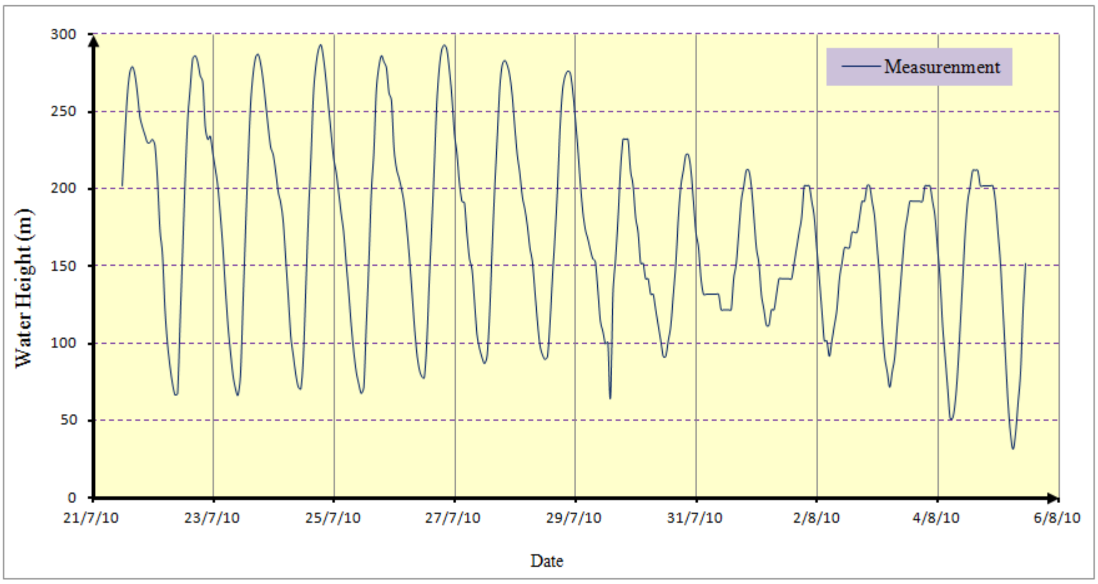

Figure 3. Tidal Fluctuation, (Priohandono, et. all, 2010)

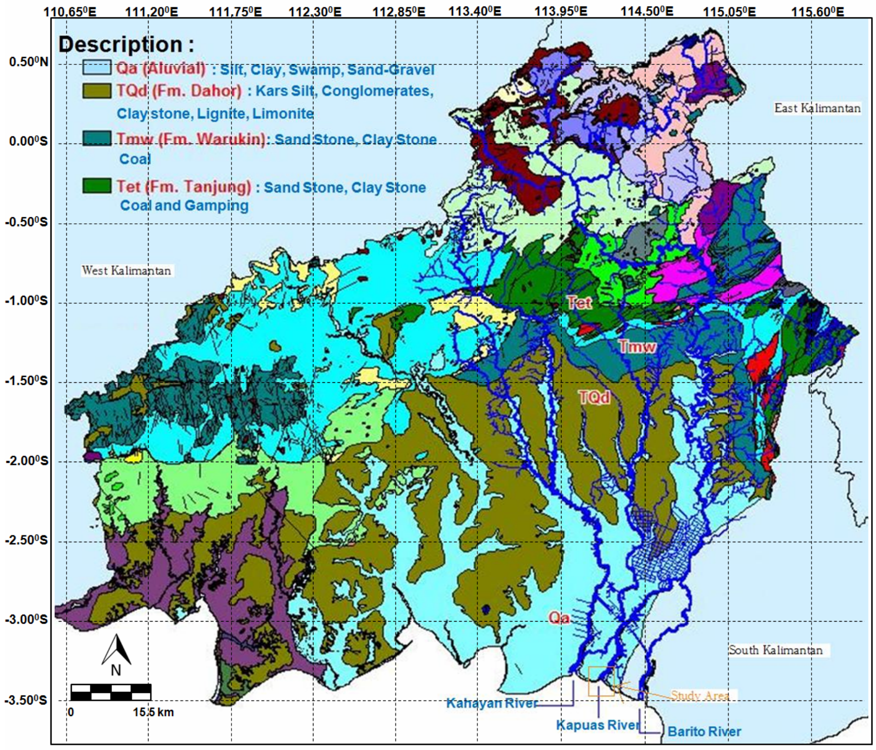

Figure 4. Geological Map, (Sikumbang, 1994)

2007). Mesh generators consist of three phases, a definition of the model boundaries-closed boundaries (land-water) and open boundaries, generating a depth-independent mesh and refining the mesh by scaling the element areas.

Hydrodynamics approach by (DHI, 2007) describe as follow, where the shallow water equations could be presented by integration of the horizontal momentum equations and the continuity equation over depth $h=\eta+d$

However, in numerical model of shallow water equations the integral form of the system of shallow water equations can in general form be written as

$$\frac{\partial \boldsymbol{U}}{\partial t} + \nabla \cdot \boldsymbol{F}(\boldsymbol{U}) = \boldsymbol{S}(\boldsymbol{U})$$

Where U is the vector of conserved variables, F is the flux vector function and S is the vector of source terms. While, in Cartesian co-ordinates the system of 2D shallow water equations can be written below,

$$\frac{\partial \boldsymbol{U}}{\partial t} + \frac{\partial\left(\boldsymbol{F}_x^I - \boldsymbol{F}_x^V\right)}{\partial x} + \frac{\partial\left(\boldsymbol{F}_y^I - \boldsymbol{F}_y^V\right)}{\partial y} = \boldsymbol{S}$$

Where the superscripts I and V denote the in viscid (convective) and viscous fluxes, respectively and where

$$\boldsymbol{U} = \begin{bmatrix} h \\ h\bar{u} \\ h\bar{v} \end{bmatrix},$$

$$\boldsymbol{F}_x^I = \begin{bmatrix} h\bar{u} \\ h\bar{u}^2 + \frac{1}{2}g(h^2 - d^2) \\ h\bar{u}\bar{v} \end{bmatrix}, \quad \mathrm{F}_x^V = \begin{bmatrix} 0 \\ hA\left(2\frac{\partial \bar{u}}{\partial x}\right) \\ hA\left(\frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial x}\right) \end{bmatrix}$$

$$\boldsymbol{F}_y^I = \begin{bmatrix} h\bar{v} \\ h\bar{v}\bar{u} \\ h\bar{v}^2 + \frac{1}{2}g(h^2 - d^2) \end{bmatrix}_a, \quad \mathrm{F}_y^V = \begin{bmatrix} 0 \\ hA\left(\frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial x}\right) \\ hA\left(2\frac{\partial \bar{v}}{\partial x}\right) \end{bmatrix}$$

$$\boldsymbol{S} = \begin{bmatrix} 0 \\ g\eta\frac{\partial d}{\partial x} + f\bar{v}h - \frac{h}{\rho_0}\frac{\partial p_a}{\partial x} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x} - \frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) \\ + \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} + hu_s \\ g\eta\frac{\partial d}{\partial y} - f\bar{u}h - \frac{h}{\rho_0}\frac{\partial p_a}{\partial y} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y} - \frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) \\ + \frac{\tau_{sy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} + hv_s \end{bmatrix}$$

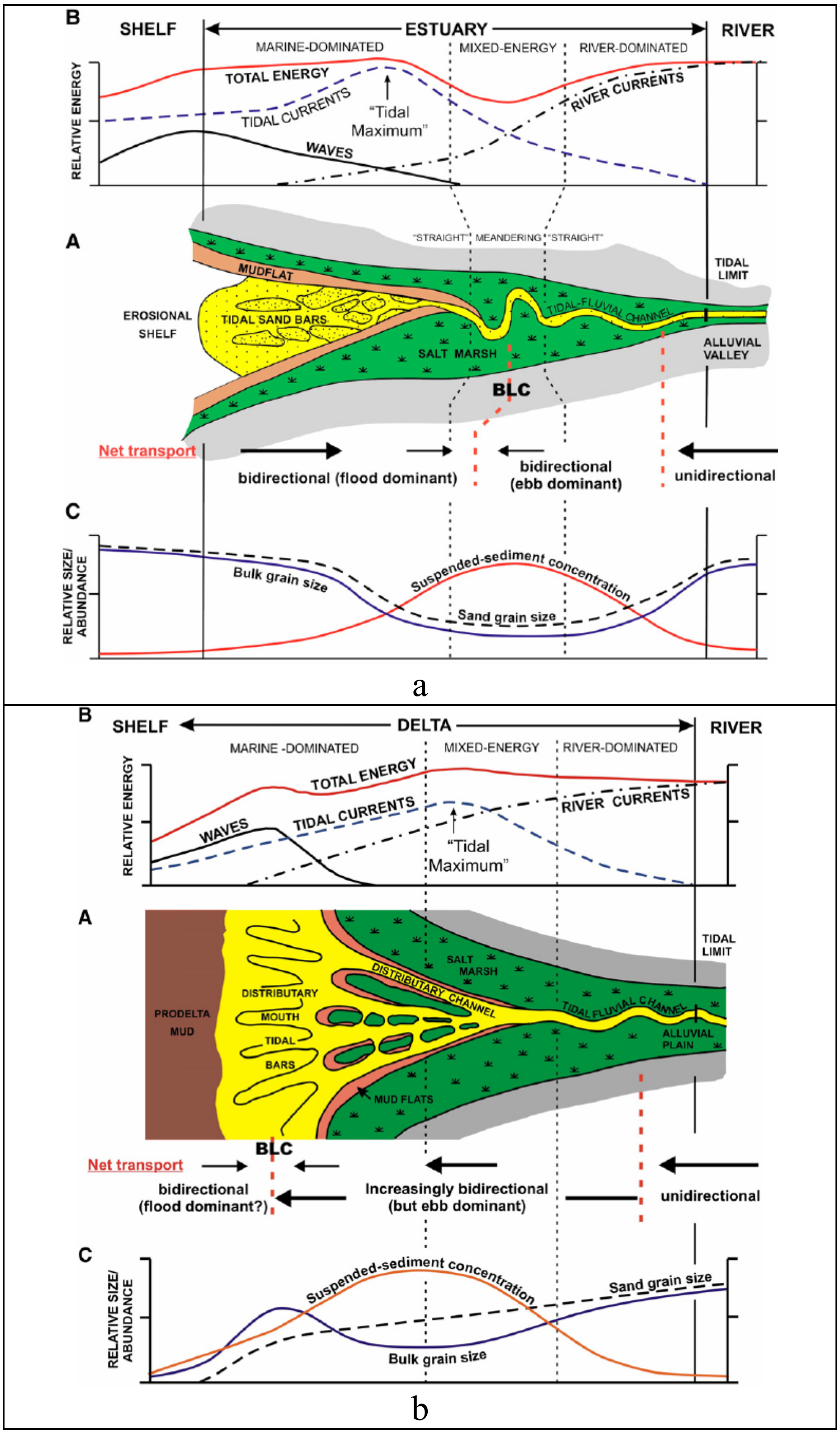

Figure. 5. River Mouth Conditions, (Dalrymple, 2007)

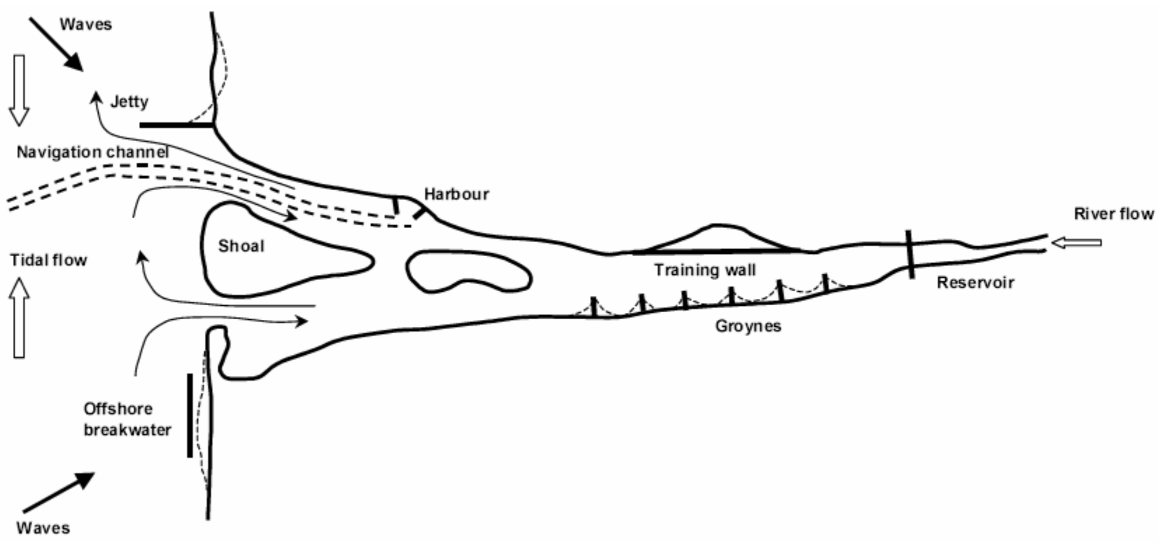

Figure 6. Problem in Estuary Area (Van Rijn, 2004)

Fluxes at interface of the cells could be calculated using Roe's scheme (Roe, 1981) who assumes the scheme the dependent variables to the left and to the right of an interface have to be estimated. Nevertheless, the average gradients are estimated using the approach by Jawahar and Kamath, 2000. In addition, to avoid numerical oscillations a second order TVD slope limiter (Van Leer limiter, see Hirsch, 1990 and Darwish, 2003) is used.

Vertical eddy viscosity would be approach by Munk-Anderson formulation (Munk and Anderson, 1948) and horizontal eddy viscosity would be applied by (Smagorinsky,1963).

A bottom stress is determined by a quadratic friction law that the depth average velocity and the drag coefficient can be determined from the Chezy number, *C*, or the Manning number, *M*.

As describes in DHI (2007) the governing equation behind MT module are essentially based on Mehta et al. (1989). Since the cohesive sediment transport module or mud deals with the movement of mud in a fluid and the interaction between the mud and the bed. The transport of the mud is generally described by the following equation (e.g. Teisson, 1991)

$$\frac{\partial c^i}{\partial t} + \frac{\partial uc^i}{\partial x} + \frac{\partial vc^i}{\partial y} + \frac{\partial wc^i}{\partial z} - \frac{\partial w_s c^i}{\partial z} =$$

$$\frac{\partial}{\partial x}\left(\frac{\upsilon_{Tx}}{\sigma^i_{Tx}}\frac{\partial c^i}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\upsilon_{Ty}}{\sigma^i_{Ty}}\frac{\partial c^i}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\upsilon_{Tz}}{\sigma^i_{Tz}}\frac{\partial c^i}{\partial z}\right) + S^i$$

The formula above describe t as time; u,v,w are flow velocity components; ∂_v is vertical turbulent (eddy) diffusion coefficient; c^i is the i'th scalar component (defined as the mass concentration); w_s^i is fall velocity; σ^i_{Tx} is turbulent Schmidt number; ν_{Tx} is anisotropic eddy viscosity; S^i is source term.

The deposition is described by (Krone, 1962) where deposition (S_D) is resulted from w_s settling velocity (m/sec), c_b suspended sediment concentration near the bed and p_d probability of deposition as follow;

$$S_D = w_s c_b p_D \quad \text{and} \quad p_d = 1 - \frac{\tau_b}{\tau_{cd}}$$

The erosion consist two modes sediments which are hard bed and soft bed. Within a hard bed, a bed consolidation of the erosion rate can be used (Partheniades, 1965) while the soft bed the partly consolidated bed the erosion rate can be applied from (Parchure and Mehta, 1985).

Based on information above, the field data such as water depth of the river, water depth of the coastal, type of sediment, current speed would be analyzed within Software Mike 21 as we can see in flowchart at Figure 7. The bathymetry data in xyz format have been imported to Software Mike 21 and flexible mesh was created automatically by the software, Figure 9.

A two-dimensional (2D) flexible mesh of Kapuas Murung river mouth model is carried out as shown in Figure 8. The workspace projection is in WGS 1984 UTM Zone 50S and open boundaries condition are applied at the southern of the FM model considering

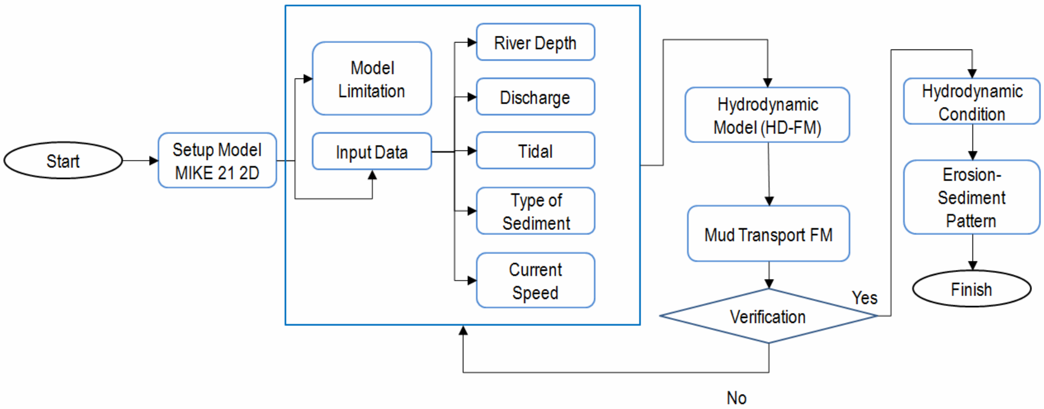

Figure 7. Flow chart of Model Analysis

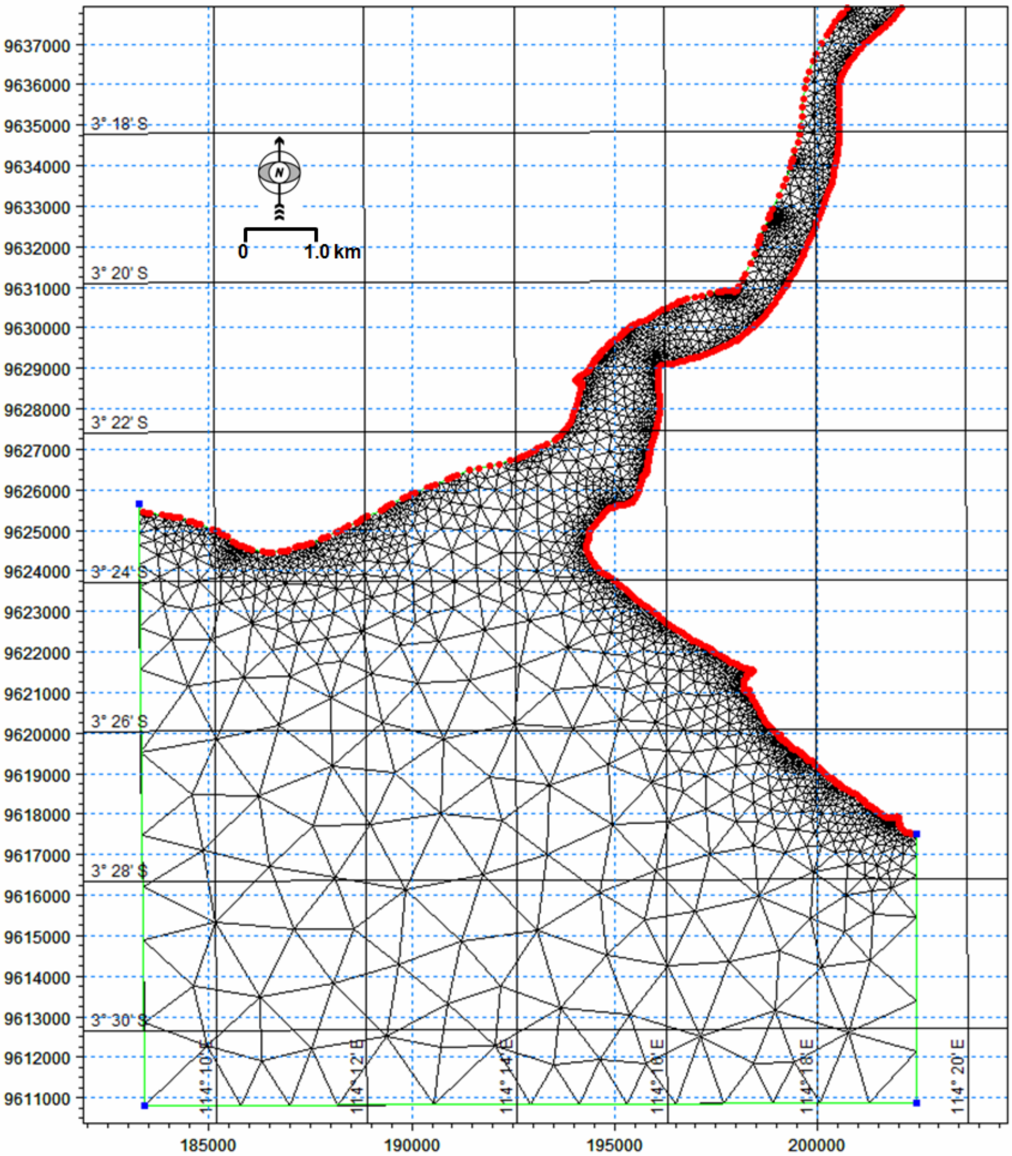

Figure 8. Flexible Mesh Design around River Mouth

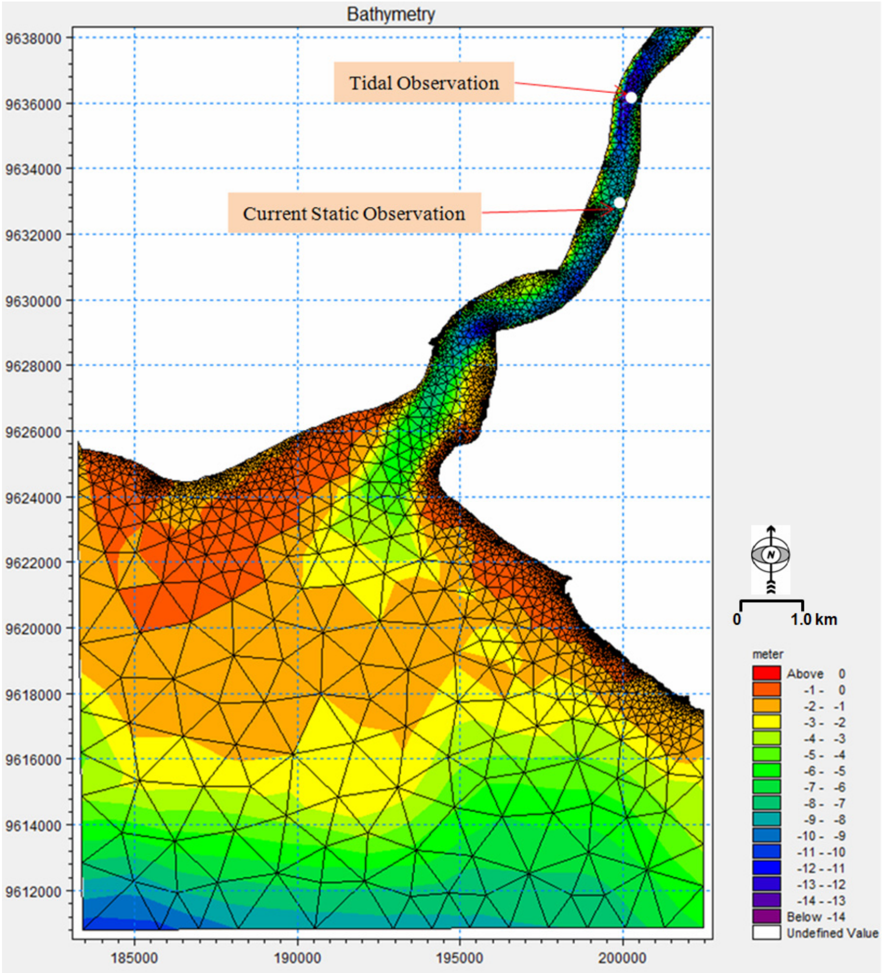

Figure 9. Bathymetry of Flexible Mesh

tidal force come from 14 meter water depths. The other boundaries, the western and eastern parts of the model have a distance about 7.5 km from the centre of the river mouth.

RESULTS

The original bathymetry could be seen in Figure 2, furthermore the water depth condition around river mouth is replaced in model as can be seen in Figure 9. The flexible meshes around coastline have much more refined than the mesh in the offshore. This condition is adjusted by the water depth data which yielded from survey is very dense.

The boundaries consist of two types of the edge which are the land boundary and open boundaries. The land boundary is the edge of the coastline or the riverside and the water while the open boundary is the edge of water in the model so the model would be analyzed only within those boundaries.

The mesh file that yielded by mesh generator is an ASCII file that includes information of the geographical position and water depth at each node point in the mesh, DHI 2007. Mesh generator consist of three phases, viz : a definition of the model boundaries-closed boundaries (land-water) and open boundaries, generating a depth-independent mesh and refining the mesh by scaling the element areas.

Models are distinguished by two general monsoon of dry and wet season. Within dry season the river discharge is assumed having a smaller value than wet season. The number of river discharge was obtained using rational method, Mulvaney (1851) and updating by Kuichling (1889) and Lloyd-Davies (1906). The rational method would calculate a velocity of the river flow and watershed drainage area. A mean water level in a cross section of the upstream within dry and wet condition would be used as basic parameter to calculate the river discharge. Based on (Priohandono, et. al, 2010) the cross section has watershed drainage area 120,000 m^2 and 132,000 m^2 for dry and wet respectively. The mean water flows about 1.14 m^2/s besides, mean water depth of wet condition is assumed

Table 1. Input Parameters of the models

No	Description	Wet Period	Dry Period
1	Time Simulation (days)	15	15
2	Maximum Time Step (sec)	30	30
3	Bathymetri	Kapuas-bati-2010.mdf	Kapuas-bati-2010.mdf
4	Density Type	Barotropic	Barotropic
5	Critical CFL Number	0.8	0.8
6	Initial bed Condition	0	0
7	Forcing Flow (m^3/sec)	13680	4560
8	Tidal Component	M2, S2, O1, K1, N2, P1, K2, Q1	M2, S2, O1, K1, N2, P1, K2, Q1
9	Velocity	Current meter data	Current meter data
10	Manning Number	25	25
11	Viscosity	0.1	0.1
12	Coriolis Forcing	Varying in Domain	Varying in Domain
13	Number of Fractions	1	1
14	Number of Layers	2	2
15	Deposition-Critical Shear Stress (N/m^2)	0.1 and 0.25	0.1 - 0.25
16	Mud Type Erosion	Layer 1-Soft Mud Layer 2-Hard Mud	Layer 1-Soft Mud Layer 2-Hard Mud
17	Time Simulating	40 Hours using 3.2 GHz i3 with 4 GB Memory	35 Hours using 3.2 GHz i3 with 4 GB Memory

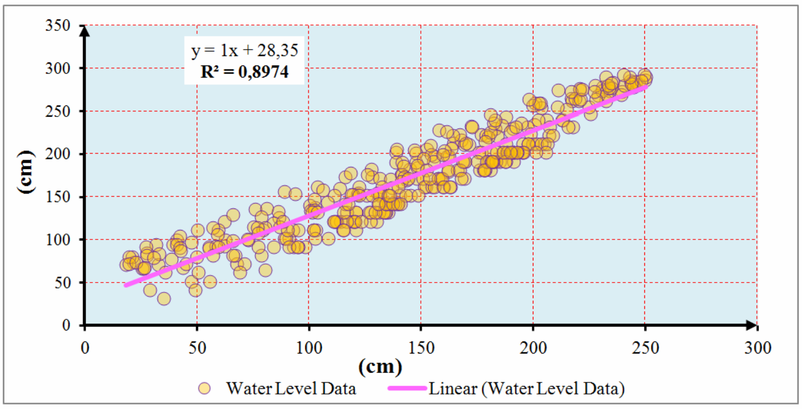

Figure 10. Water Level Verification

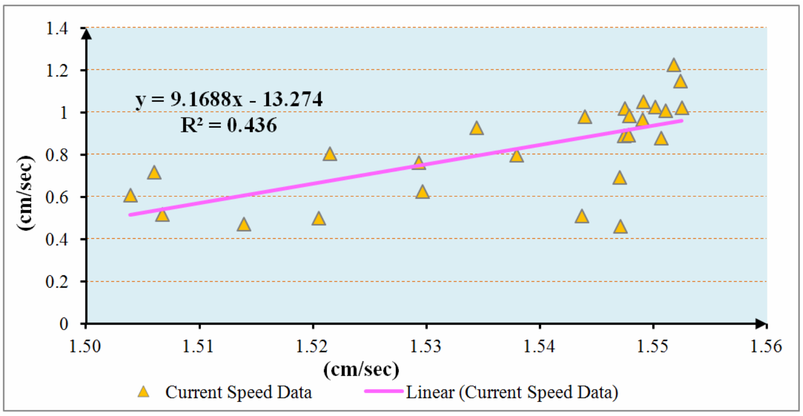

Figure 11. Current Speed Verification

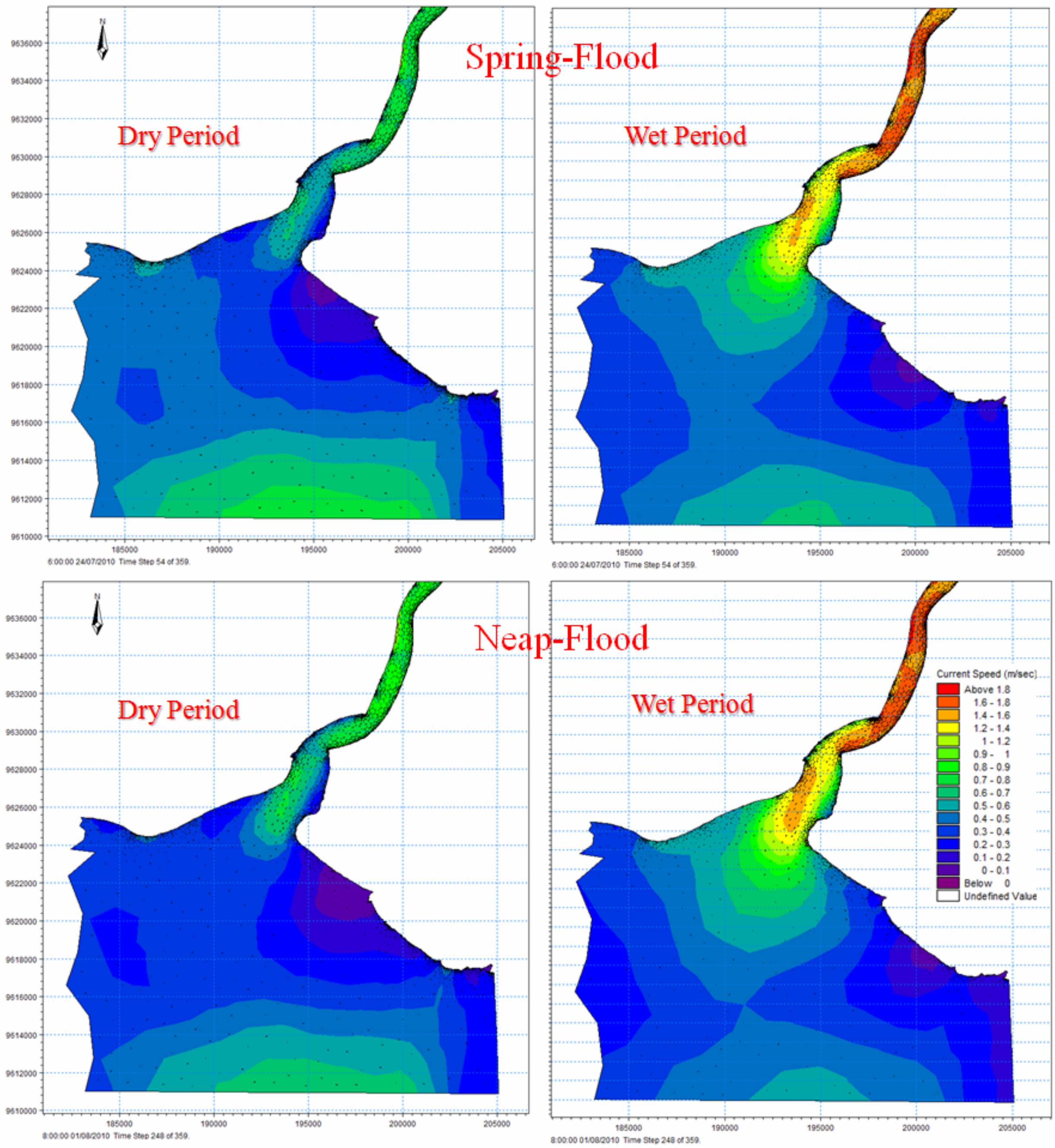

Figure 12. Current Speed (Flood Condition)

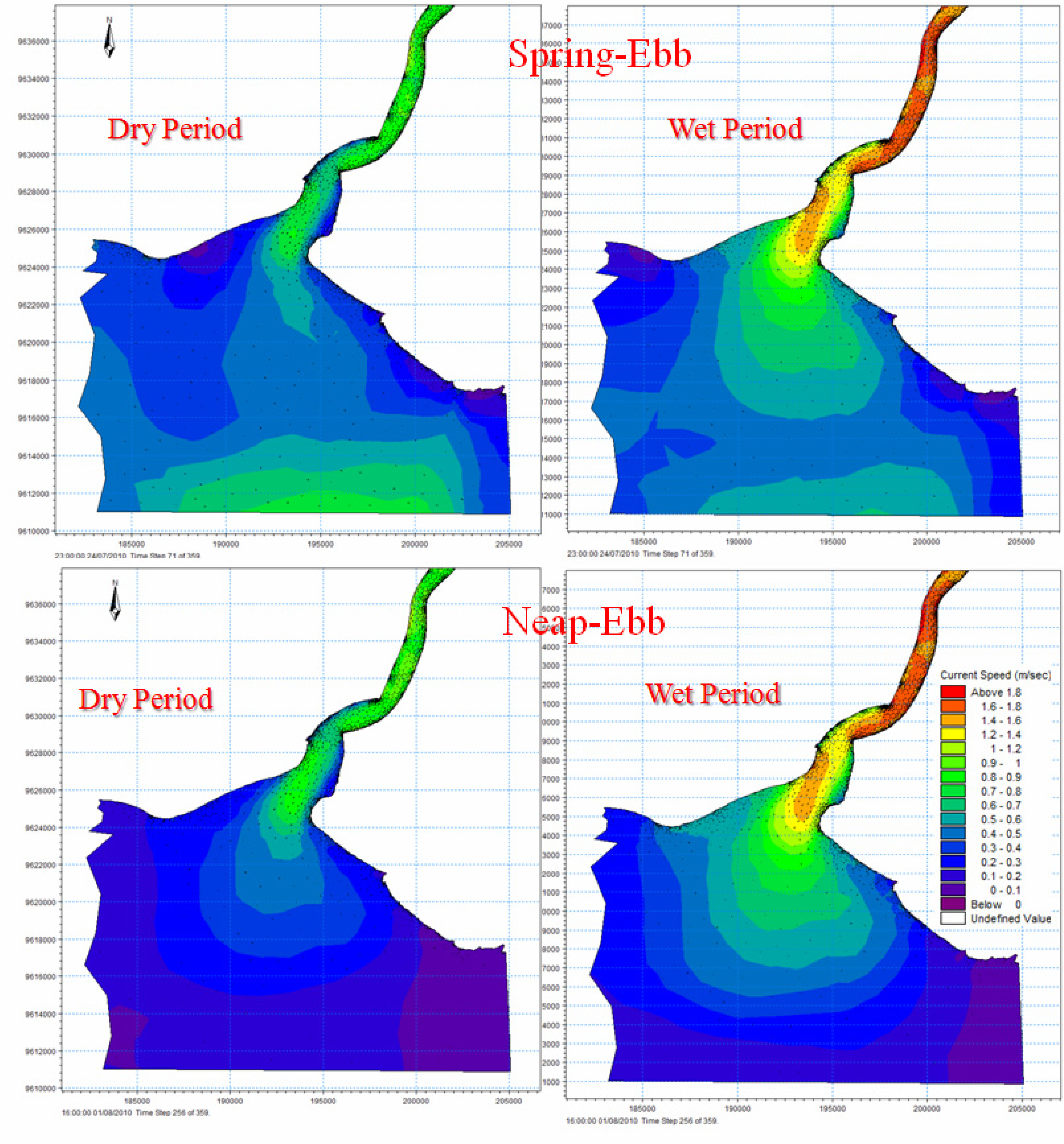

Figure 13. Current Speed (Ebb Condition)

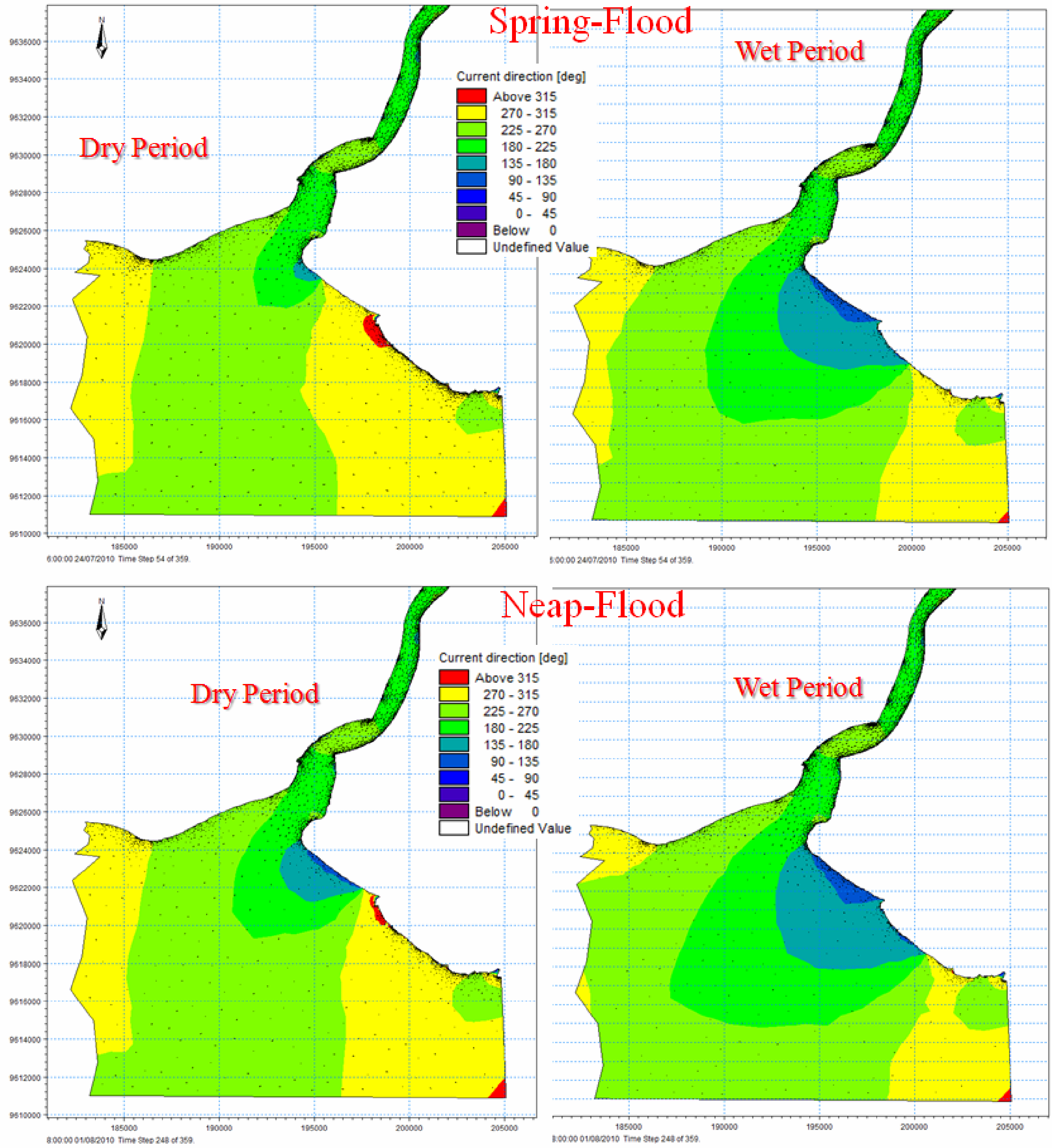

Figure 14. Current Direction (Flood Condition)

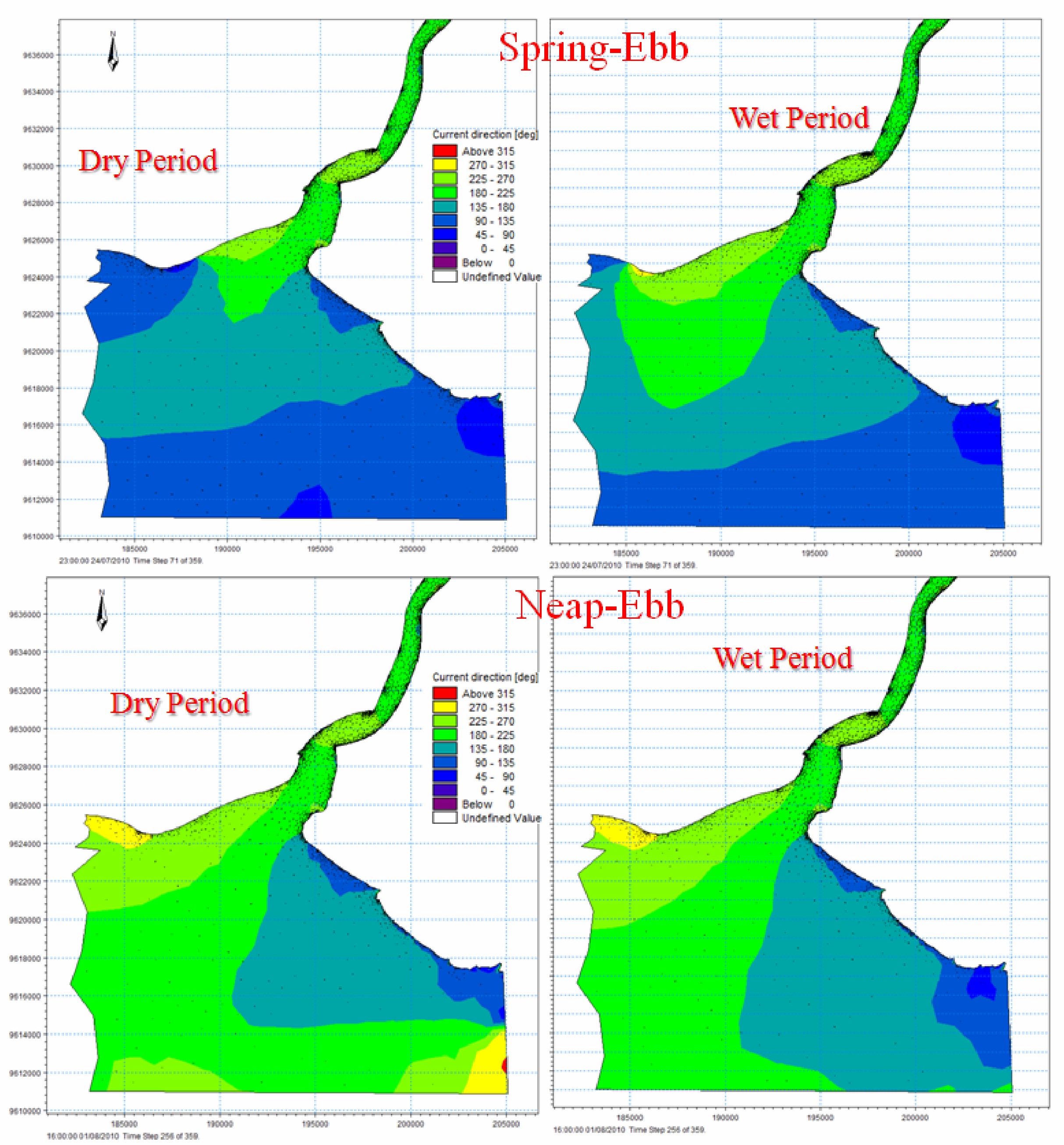

Figure 15. Current Direction (Ebb Condition)

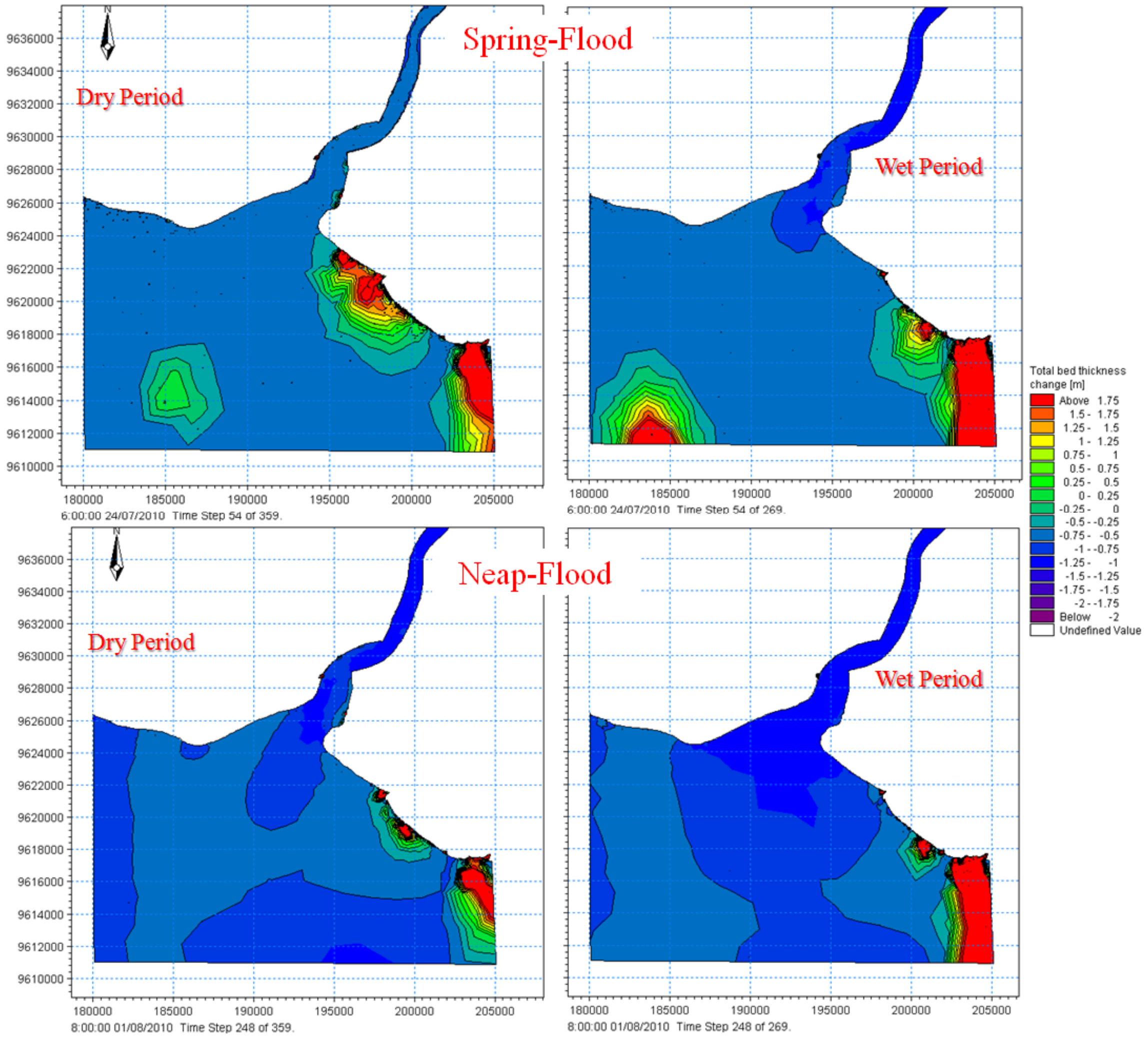

Figure 16. Erosion and Sedimentation Pattern at River Mouth in Flood Condition

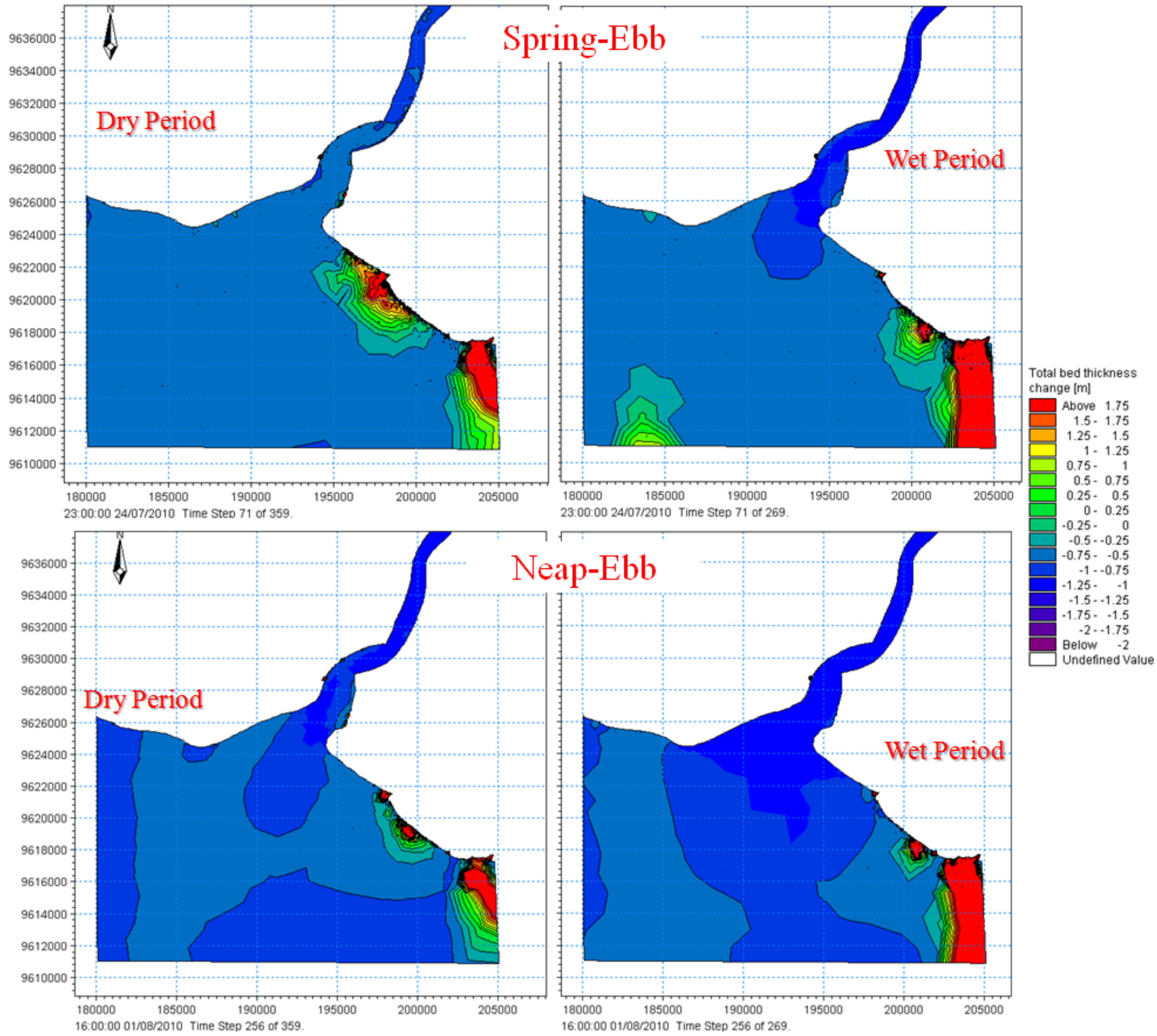

Figure 17. Erosion and Sedimentation Pattern in Ebb Condition

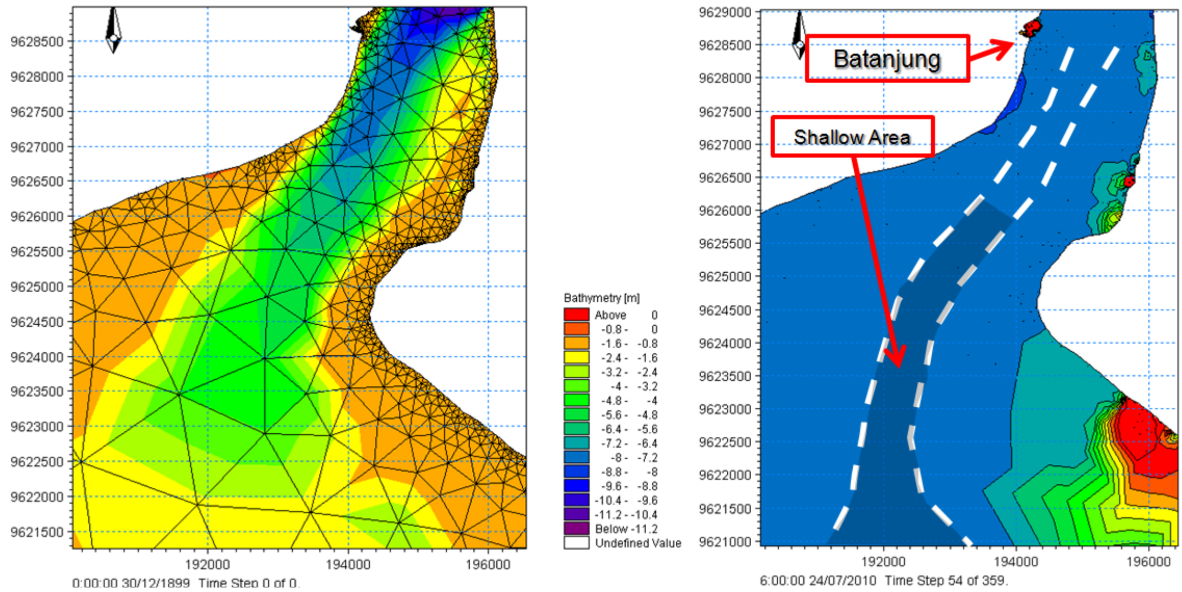

Figure 18. River Mouth Condition of Kapuas Murung River

condition. It is about 0.3 – 0.45 m/sec for the average but the maximum is lesser than flood condition which attains ± 0.806 m/sec Figure 13. In wet period ebb condition the maximum water speed still can be found along the upstream with the maximum water speed reaches ±1.78 m/sec.

Based on current speed of ebb conditions it could be seen that the low water speed happened 5 km along coastline at eastern part of the river mouth. However, the current speed in dry period ebb condition, at the centre of a river mouth has been increase from 0.4-0.5 cm/sec to 0.5-0.6 m/sec.

Current directions along the river when a flood condition could be said have the same pattern that are all go south (180 -225) and southwest (225 -270). It is also happened in the coastal area where the dominant directions are going to south (180 -225) and west (270 -315), Figure 14. Furthermore, current directions of ebb condition have different pattern where the coastal area have dominant from east (90 -135) and south east (135 -180) directions, Figure 15.

Total bed thickness changed due to spring-flood condition that shows the pattern of sedimentations is dominantly occurred at eastern part of the river mouth, (Figure 16). These phenomena also take place at neap-flood condition where the most deposition could be found in the right side of the model (Figure 16). The maximum deposition in spring-flood and neap-flood reach about 1.75 m although the position of the sedimentation would be moved to south and eastern part.

In addition, the sediment transport at spring-ebb and neap-ebb condition present a pattern of total bed thickness changed smaller than flood condition, Figure 17. Much more erosion could be found in the dry period which is not only in spring circle but also in neap circle where the erosion is much higher than in flood condition. The sedimentation patterns in this conditions show took place in the same area but it is not happened in the ebb condition where the erosion spread to all model area.

Furthermore, Batanjung where the port would be built have a pattern which tends to high deposition that shows the suspended sediment concentration near this area have values from 0.5 to 0.6 kg/m3. However, the river mouth condition shows the western part of the river mouth faces a minimum transformed while the eastern part has a big changed, Figure 18. Additionally, the vessel should be aware with a shallow area in front of the river mouth that would be used as navigation channel. The draft design of the vessel might be considered to manage a water depth along the navigation channel.

DISCUSSION

As mention before, the verification result of the current seed yielded a small value that caused by the error when data was collected. It was occurred caused by the limitation of the tools, as mention before, the tools is a current meter stick by velaport so when the tool was lowered to the water the stick could not measure the perpendicular of the flow hence the flow condition could not recorded properly. In the future, it should be used other tools such as ADCP to measure the current speed in the river.

Wind and wave conditions would be applied in next survey to obtain the robust results of the simulations. It might be interest to predict the wind-wave effect in the river mouth due to a hydrodynamic circulation in the model. We could predict the wind-wave affects the level of sedimentation and erosion pattern. Considering the once time collecting data of a sediment concentration therefore it should be taken another collecting data in different period to see how much the concentrations in the river.

CONCLUSIONS

Based on the simulation models, some results could be conclude as below,

- Current speeds around the river mouth highly depend on the river discharge that present the dominant current direction near the river mouth is going to south and south west.
- Mud transport model was chosen to analyze erosion and sedimentation pattern caused by considering a lithology of alluvium Qa that contained at catchment area.
- The dominant sediment pattern occurred in eastern part of river mouth for all flood scenarios with the large area but in the ebb scenarios the sedimentation result a smaller area.
- The sedimentation around river mouth accumulates at Batanjung and the eastern part of river mouth
- The vessel dimension must be consider about the water depth and the sediment pattern around the river mouth.

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