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Modeling of water mass flow patterns at the Mahakam River and its sub-river of the Karang Mumus River

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Abstract
The purpose of this research is to model the flow pattern of water masses by considering the upstream discharge and the tidal elevation downstream. The research activity is conducting field observations as inputs needed in numerical simulations. Field observations included the upstream discharge of the Mahakam River and the ebb and flow of the Karang Mumus river estuary. The results showed that the tides at the confluence of the Mahakam River and the Karang Mumus River had mixed tidal types, which tended to be double daily. The current pattern at the confluence of rivers is strongly dominated by currents from the Mahakam River. Upstream one-way flow occurs at high tide and two-way downstream flow occurs when the tide is low. The two-way flow is caused by the slowing flow when the Mahakam River flows into a dam on the downstream flow of the Karang Mumus River which will come out.

Keywords: tidal levels, currents, and numerical modelling

Introduction
In general, each river flow has characteristics and forms that are different from one another, not to mention the confluence between the Mahakam River and the Karang Mumus tributary. Several studies have been carried out in the Karang Mumus River, such as flow characteristics (Nur A. *et al* (2019)) [8, 9, 10], preliminary mixing (Nur A. *et al* (2019)) [8, 9, 10], deposition (Nur A. *et al* (2019)) [8, 9, 10], long wave dynamics analytical approach in the estuary (I Raming. *et al* (2019)) [12]. Hydrodynamic modeling has also been carried out by several previous studies on rivers and estuaries, such as velocity distribution modeling (Arafat Y. *et al* (2016)), tidal effects (Hatta M P. *et al* (2018)), salinity and temperature (Karamma *et al*. 2018)) [4, 5], Karma. *et al* (2020)), and control of sediment texture and topography on the coast in morphodynamic conditions (Suriamihardja D.A. *et al* (2015)) [13]. The current pattern of one of the generators is a tidal wave. Tides have three main consequences (N. Leonardi. *et al* (2015)) [6] mixing is increased, and the buoyancy effect is partially suppressed, the river-ocean interface moves in both vertical and horizontal directions, and bidirectional sediment transport is present. When the tide enters the river, its behavior is like a wave that rises upstream, diverges, and eventually disappears due to the friction of the bottom and the flow of the river. The tides from the sea enter the Mahakam River as far as 140 km (I. Mandang and T. Yanagi. (2008)) [7]. While Samarinda is 60 km from the sea. The tides from the sea carry the mass of water. This study aims to model the flow pattern of water masses with a 2D numerical model at the confluence of the Mahakam River and the Karang Mumus tributary based on the hydrodynamic effect of discharge from upstream and tides from downstream.

Research Methods
Research Sites
The area that is the research location includes the Karang Mumus River which is limited upstream by the Benangga Weir to the downstream which meets the Mahakam River, see Figure 1.

Hydrodynamic Modeling
The parameters used in current modeling using the MIKE 21 Hydrodynamic Module software are inputting tidal time series data, and bathymetric mesh data will produce outputs in the form of current velocity, current direction, mass density, coefficient of resistance, vortex viscosity, Q flux, and u velocity in the form of area and point series. Current simulation parameters are entered with a simulation duration of 15 days on June 14 - June 28, 2018 with 360 steps and Time range / step: 3600 seconds / step so that the Simulation output is 360 hours.

1. *Data entry*:
   Tidal time series data and bathymetric mesh
2. *Solution Technique*:
   Shallow water equations Time and Space using High Order. The minimum time is 0.01 (seconds); maximum time is 3600 (seconds) and Critical CFL is 0.8 and the Transport equations Minimum time used is 0.01 (seconds), Maximum time is 3600 (seconds) and Critical CFL is 0.8

3. *Flood and Dry*:
   Because the model is located in an area where flooding and drying often occur, this model uses flood and dry facilities. If the water depth is less than the wetting depth it will be taken into account again, and only if the water depth is less than the drying depth will the element be removed from the simulation. Flooding depth is used to determine a flooded element (re-entered into the simulation calculation).

a. *Drying depth*, i.e. the depth that is considered dry: 0,001 m
b. *Flooding depth*, i.e. the depth that counts again: 0,05 m
c. *Wetting depth*, i.e. the depth that is considered wet: 0,1 m

4. *Eddy Viscosity:*
   Eddy type, *Smagorinsky formulation*: 0,28 m^2/dt considered as *constant* (*default*)
5. *Bed Resistance*:
   Resistance type, *Chezy number*: 32 $m^{1/3}$ dt constant value, selected after calibrating the tides.
6. *Boundary Condition (BC):*
   Current and salinity modeling design by entering tidal time series data, bathymetric mesh data, salinity data. The boundary conditions made, namely:
   BC-1 use land,
   BC-2 using tidal observation data,
   BC-3 using the value of the current velocity of the Mahakam River as an observation; and
   BC-4 using the value of the current velocity of the Karang Mumus River as a result of observations.
7. Other unmentioned parameters follow the default values.

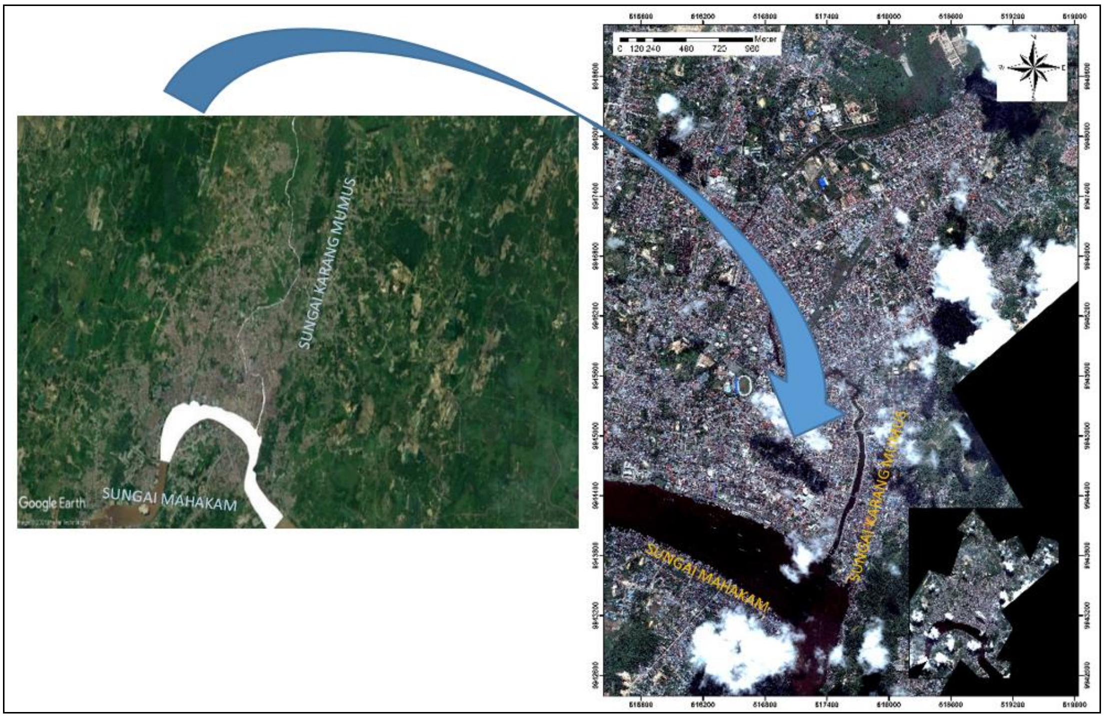


Fig 1: Map of the Confluence of the Mahakam River and the Karang Mumus. Sub-River

Data Preparation

The terrain data used is the result of field bathymetry measurements for the depth of the Karang Mumus River to the confluence of the Mahakam river while for land topography data obtained from Demnas data as more detailed terrain data. The results of the current modeling are simulated with an hourly time span for 15 days and the changes of the model are demonstrated based on differences in color gradients. So that it is easy to observe and analyze the simulation results of the current model that occurs in the area. This modeling was carried out on 4 conditions, namely conditions towards full moon tide, towards full moon tide, towards neap tide, towards neap tide from modeling. From these results, it can be seen that the current pattern is due to the influence of bathymetry and tides.

Results and Discussion

Bathymetry Measurement

The depth contour measurement is done using an echosounder. Measurement starts from upstream to downstream of the Karang Mumus River. The results of contour mapping are shown in Figure 2.

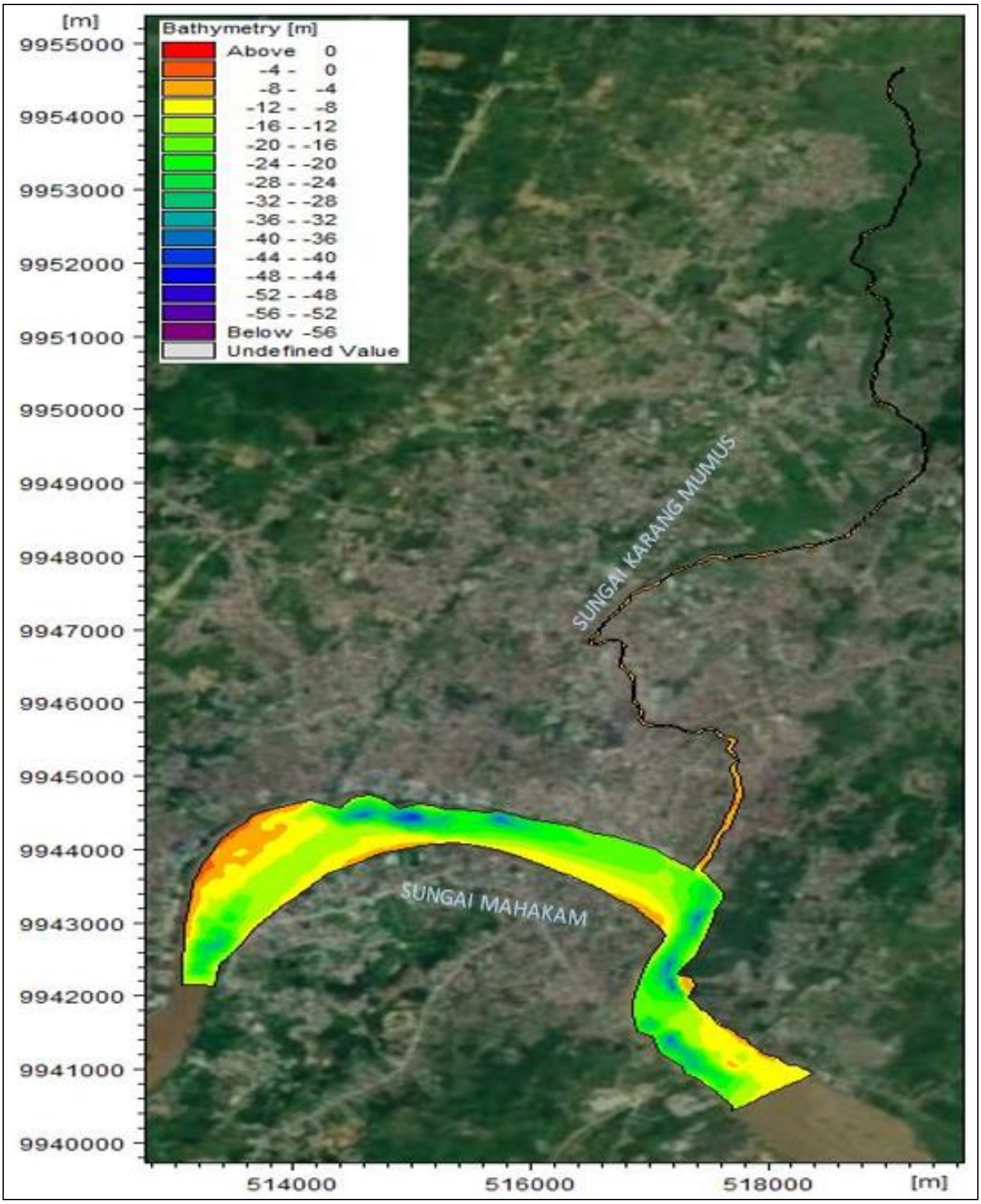


Fig 2: Confluence of Mahakam River and Karang Mumus sub River

The depth from upstream to downstream of the Karang Mumus River ranges from -1 m to -5 m as shown in Figure 2. While along the Mahakam River, the depth varies from -5 m to -48 m.

Discharge Measurement

Measurement of the discharge of the Karang Mumus River from 14 - 28 July 2018 at the Benangga weir with an average discharge of 1.8 m3/sec. The Makaham river discharge of 83.74 m3/sec is taken in the upper part of the Mahakam River which is no longer influenced by tides, namely: the Muara Kaman District area. The discharge is obtained from the measurement of the cross-section with bathymetry and the measurement of the current velocity in the cross-section at three points using a current meter with three variations of depth, then the velocity is averaged.

Tidal Measurement

Tidal measurements were carried out for 15 days from 14 to 28 July 2018 (1-15 Dzulqa'dah 1439). Measurements were made at the lower reaches of the Karang Mumus River. Tidal chart observations and analysis downstream of the Karang Mumus River can be seen in Figure 3.

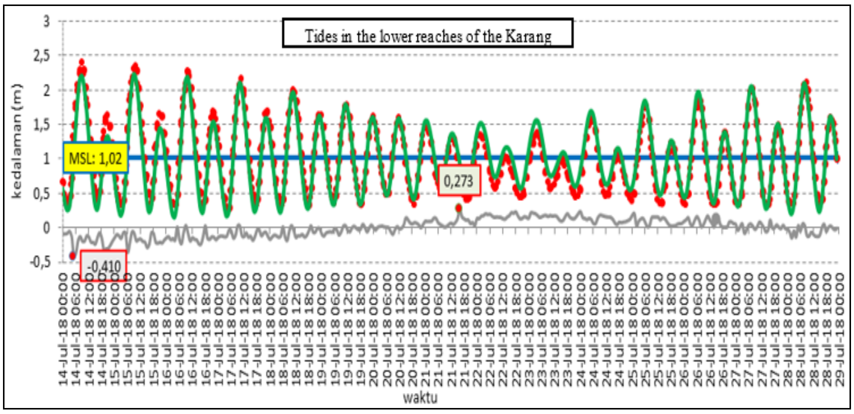


Fig 3: Tidal Graph in the Lower Reaches of the Karang Mumus River between Observations and Predictions for 15 Days Using the Least Square Method

The data from tidal observations are made to predict the height using the Least Square method. The Least Square method processes data from tidal observations into tidal constants that can be analyzed into predictions of tidal heights as shown in Table 1. The calculation of Figure 3 has a standard deviation value of 0.132.

Table 1: Tidal Constants Downstream of the Karang Mumus River

No	Component	Symbol	Downstream of Karang Mumus	
			g^o *Phase*	*H=Amplitudo (m)*
0.	*Average water level*	Z_0		1,0188
1.	*Main lunar constituent*	M_2	89,08°	0,5535
2.	*Main solar constituent*	S_2	221,33°	0,0180
3.	*Lunar constituent, due to Earth-Moon distance*	N_2	225,95°	0,0352
4.	*Soli-lunar constituent, due to the change of declination*	K_2	25,74°	0,2856
5.	*Soli-lunar constituent*	K_1	271,56°	0,4959
6.	*Main lunar constituent*	O_1	197,17°	0,1807
7.	*Main solar constituent*	P_1	131,10°	0,4188
8.	*Main lunar constituent*	M_4	274,00°	0,0267
9.	*Soli-lunar constituent*	MS_4	212,11°	0,0389

The results of the nine tidal constants in Table 1 show the phase and amplitude differences for the lower reaches of the Karang Mumus River. Phase and amplitude are used in calculating the type of tide and water level. The water level and Formzhal number observed are shown in Table 2.

Table 2: Water Level and Formzhal Numbers Downstream of the Karang Mumus River

Location	F	HAT (cm)	HWS (cm)	MHWS (cm)	MSL (cm)	MLWS (cm)	LWS (cm)	LAT (cm)
Downstream of Karang Mumus	1,18	226,70	159,04	155,43	101,88	48,33	44,73	-22,93

The results of the Formzhal number indicate a mixed type, with semidiurnal dominance as shown in Table 2. Meanwhile, the water level is used to make the tides from observations as in Figure 4.

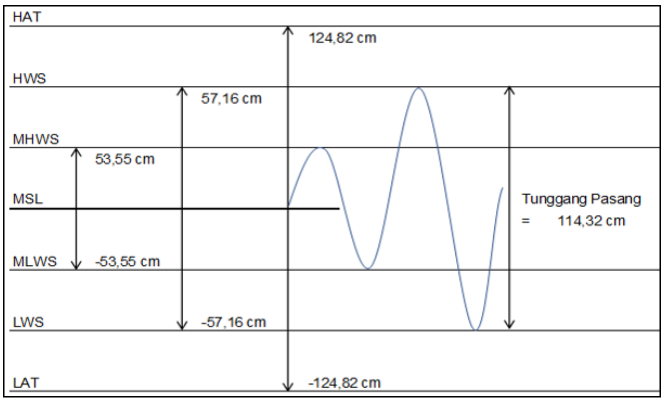


Fig 4: Tides at Downstream of the Karang Mumus River as big as 114,32 cm

Figure 4 shows the water level downstream of the Karang Mumus River with a tidal mount of 114,32 cm.

Current Measurement

Measurement of currents using a current meter has been carried out at the confluence of the Mahakam River and the Karang Mumus River taken at three points can be seen in Figure 5.

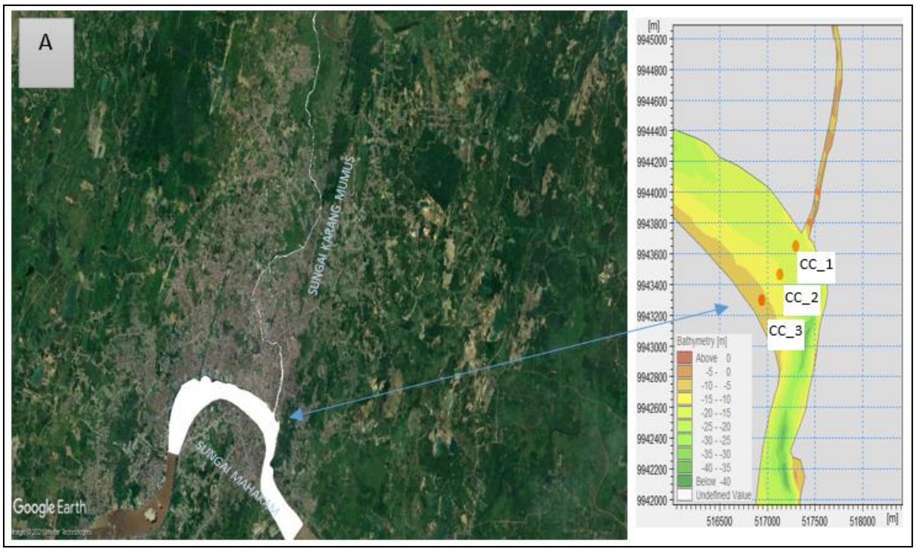


Fig 5: Current Measurement on CC_1, CC_2 dan CC_3

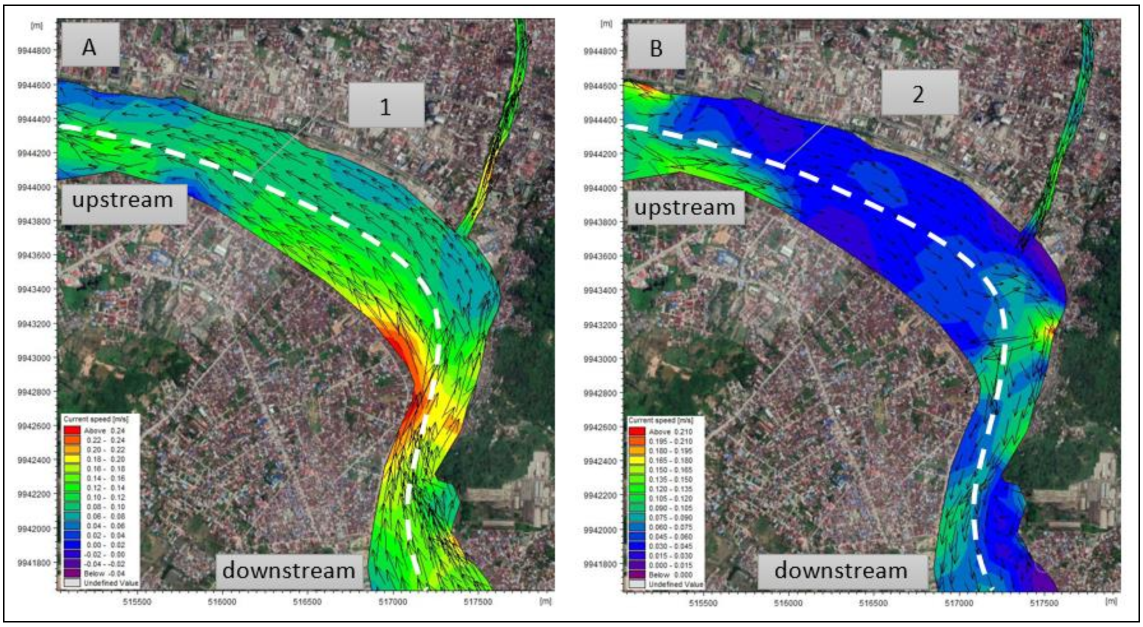
Measurements of current direction and velocity at the confluence of the Mahakam River and Karang Mumus River, namely CC_1, CC_2 and CC_3 were used for current validation at MIKE 21. The calculation of current direction and velocity for all points in Figure 5 is shown in Table 3.

Table 3: Measured Current Direction and Speed

Position	Coordinate Cartesis		Direction	Time	Average speed against depth (m/dt)
	X (m)	Y (m)			
CC_1	517239,3	9943756	186	10:30:00 AM	0,0488
CC_2	517163,6	9943536,7	145	1:50:00 PM	0,0212
CC_3	516944,8	9943210,7	149	11:00:00 AM	0,0700

Current Speed

The flow towards high tide and low tide at the full moon at the confluence of the Mahakam and Karang Mumus rivers shows that not only currents move back and forth in the Mahakam River, but also flows in and out of the Karang Mumus River with varying current speeds. The vector of the direction and speed of the current along the confluence of the river at high tide and low tide can be seen in Figure 6.



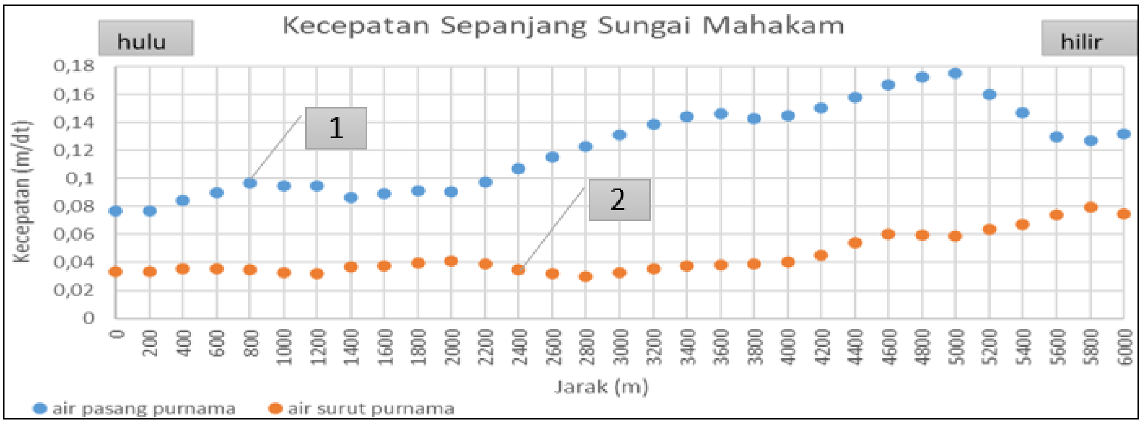
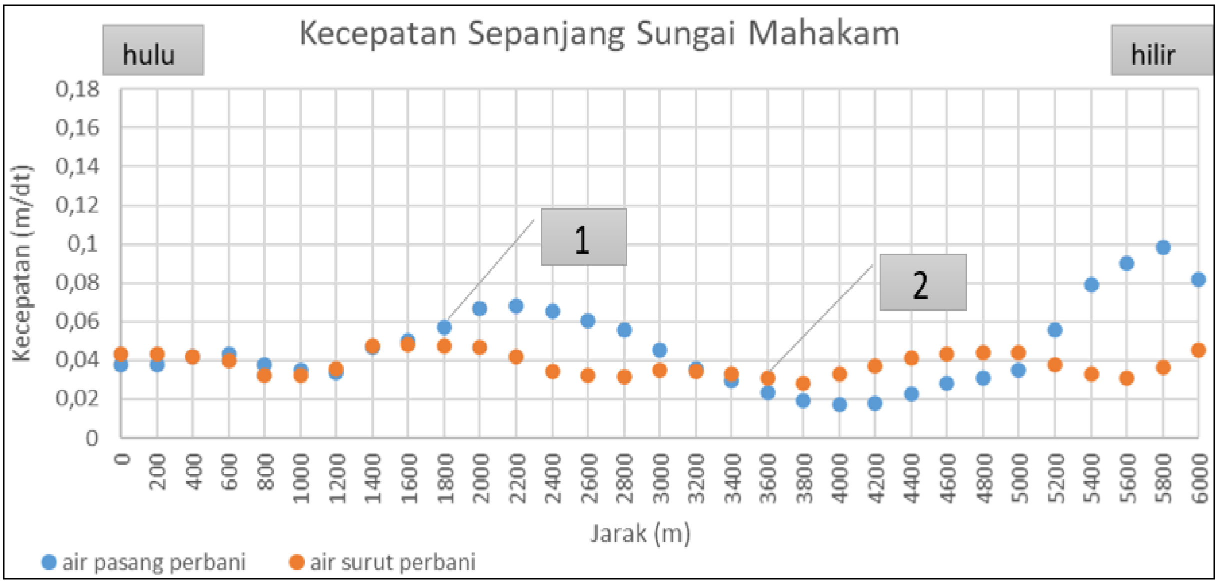


Fig 6: A. The pattern of Currents Towards High Tide at Full Tide with Speeds Ranging from 0.08 – 0.24 m/s; B. The Pattern of Currents Leading to Low Tide during the Full Tide at the Confluence of the Mahakam River and the Karang Mumus River at Speeds Ranging from 0,04 - 0,12 m/dt

Figure 6 shows the downstream velocity of the Mahakam River ranging from 0.1 to 0.2 m/s when the tide comes from the lower Mahakam River. The speed increases in the narrowing of the river cross section before heading towards the confluence of the river. The speed also increases when the tide enters the Karang Mumus River at speeds ranging from 0.12 to 0.22 m/s, because the cross section of the Karang Mumus River is smaller than the cross section of the Mahakam River. In the upper reaches of the Mahakam river there is a decrease in current velocity ranging from 0.02 to 0.16 m/s. Meanwhile, the downstream current velocity of the Karang Mumus River ranges from 0.06 to 0.15 m/s. The current that enters the Karang Mumus River comes from the stream that runs along the east bank of the Mahakam River. The outflow from the upstream of the Mahakam River ranges from 0.1 to 0.165 m/s when the water recedes at high tide. There was a two-way flow as soon as entering the meeting. First, the flow with the same speed goes directly to the west of the confluence of the river. Second, the flow slows down until it meets the outflow of the Karang Mumus River on the east side of the river confluence. The vortex occurs in the eastern area near the mouth of the river confluence. The downstream speed of the Mahakam River ranges from 0.015 – 0.09 m/s, while the downstream velocity of the Karang Mumus River ranges from 0.06 – 0.15 m/s. The lateral current velocity at high tide is greater than at low tide in the Mahakam River at full tide. The vector of the direction and speed of the current along the confluence of rivers when the tide is high and the tide is low at new tides can be shown in Figure 7.
The speed of tidal currents during the new tide at the confluence of the Mahakam River and the Karang Mumus River is in the range of 0.015 – 0.03 m/s in Figure 7-A. There is a large whirlpool due to the confluence of currents from tidal water from the lower Mahakam River and water from upstream to downstream of the Mahakam River. Variations in current velocity are seen to be small ranging from 0.015 – 0.18 m/s along the upstream part of the river confluence. The pattern of currents leading to low tide during new tides at the confluence of the river ranges from 0.015 – 0.03 m/s as shown in Figure 7-B. The Flow Velocity also looks small and similar when the tide is in, it can be seen on the graph of the current velocity laterally. At the confluence of this river, three observation points have been taken in the field to be used for current validation. Figure 8 shows a graph of the current velocity for 15 days for 3 observation points.



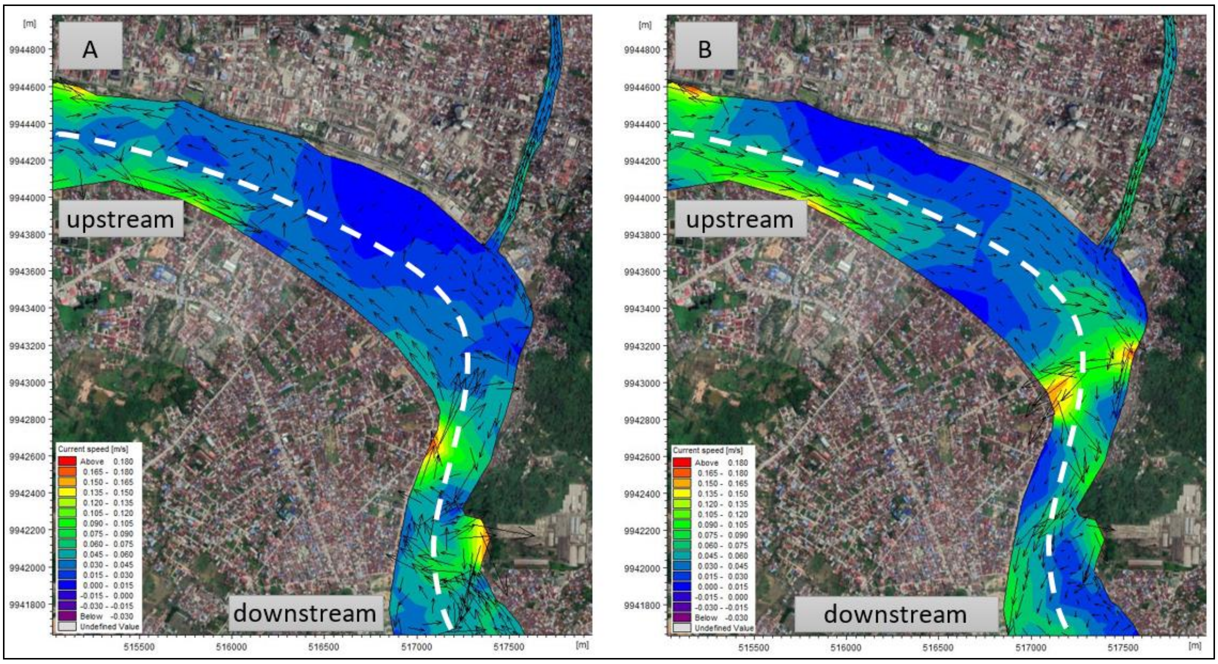


Fig 7: A. The Pattern of the Current Towards the High Tide at the Time of the New Tide with a Speed Ranging from 0.015 - 0.18 m/s; B. The Pattern of Currents Leading to Low Tide during Neap Tides at the Confluence of the Mahakam River and the Karang Mumus River at Speeds Ranging from 0,015 – 0,18 m/dt

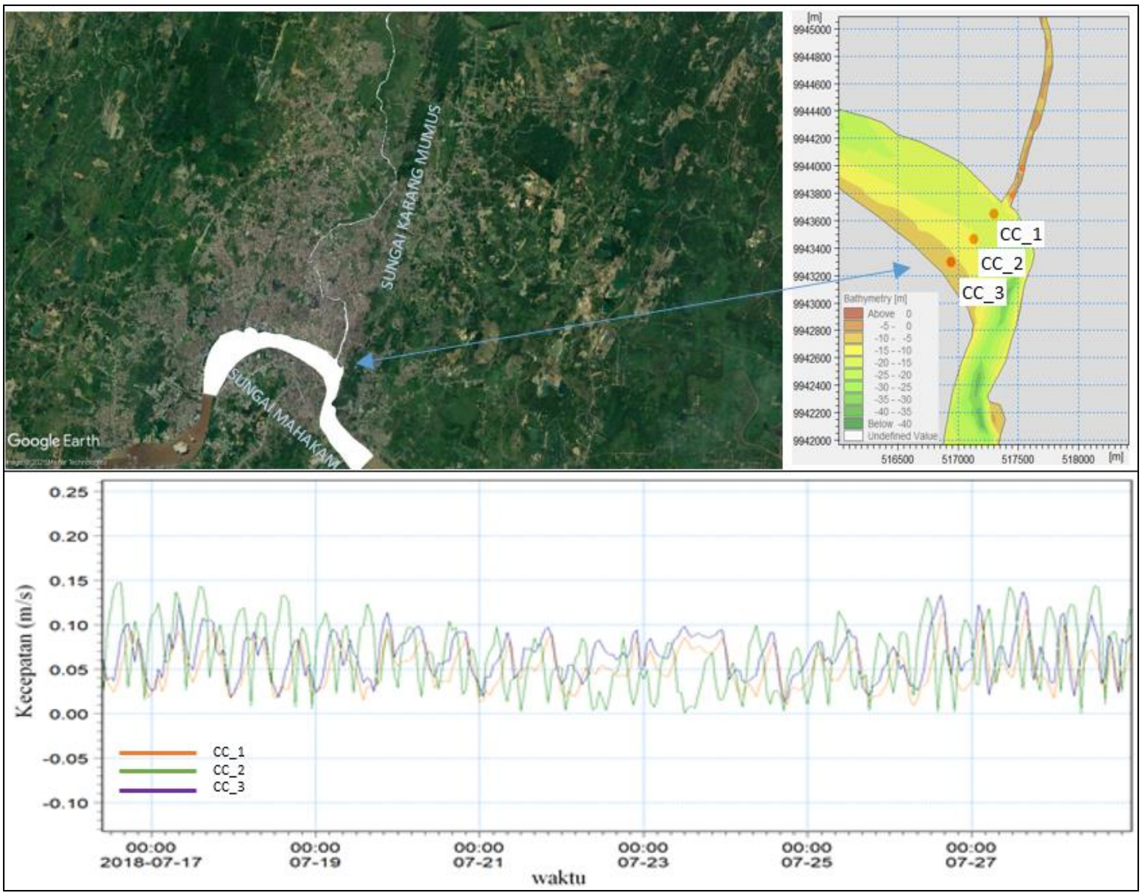


Fig 8: Current Velocity Graph for 15 Days on CC_1; CC_2 and CC_3

The graph of the current velocity for 15 days is CC_1; CC_2 and CC_3 at the Confluence of the Rivers. Velocity CC_1 is on the east side of the confluence of the river, CC_2 is in the middle of the confluence of the river and CC_3 is on the west side of the confluence of the river. The current velocity in CC_1 and CC_2 is greater than CC_3. This is because CC_1 and CC_2 are not affected by the flow of the Karang Mumus River, while CC_3 is affected by the inflow and outflow of the Karang Mumus River. Based on three current measurement points, the current simulation data is juxtaposed with the measurement data at the same date and time. The results of the RMSE flow velocity statistics at the River Confluence can be seen in Figure 9.

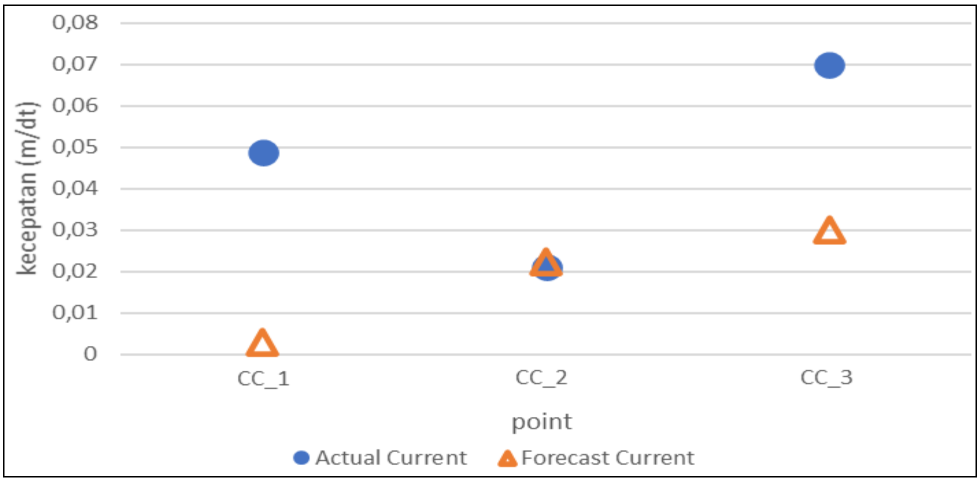


Fig 9: RMSE Current Speed $\bar{u}$ as big as 0,0614

Based on error statistics using RMSE. The results show a good fit of 0.0341 as shown in Figure 9. The results show a good fit for a modeling against the results of direct measurements in the field.

Conclusion

The tides at the confluence of the Mahakam River and the Karang Mumus River have mixed tidal types, which tend to be double daily. The current pattern at the confluence of rivers is strongly dominated by currents from the Mahakam River. Upstream one-way flow occurs at high tide and two-way downstream flow occurs when the tide is low. The two-way flow is caused by the slowing flow when the Mahakam River flows into a dam on the downstream flow of the Karang Mumus River which will come out.

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