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Numerical Simulation of Sedimentation Patterns at the Tallo River Estuary (Case Study of New Makassar Container Terminal 2)

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The increase in community activities in the Makassar waters has made the government plan long-term development by exploiting the potential of the sea through coastal reclamation, which aims to meet increasingly limited land needs, one of which is the construction of the New Makassar Container Terminal 2. This development causes changes in coastal sedimentation patterns and current patterns. This research aims to determine the flow and sediment patterns in the Tallo River Estuary due to the construction of the New Makassar 2 Container Terminal. It is simulated with a numerical hydrodynamic model using scenarios resulting from tidal measurements and wind as generators. The research results show that the flow pattern around the Tallo River Estuary before and after the construction of the New Makassar 2 Container Terminal decreased by 51.288% from 0.105 m/s to 0.051 m/s. The direction of the current at the highest tide conditions moves from the open sea towards the estuary, while at the lowest tide conditions, it moves from the estuary towards the open sea. The distribution of sediment in the waters of the Tallo River Estuary shows that changes in the basic morphology of the Tallo River Estuary tend to be high; namely, in the review lines 1 - 5, there is a change in sedimentation of 0.055 m; 0.096m; 0.048m; 0.158 m and 0.059 m. So, it can be concluded that the construction of the New Makassar 2 Container Terminal affects the water conditions in the Tallo River Estuary. The research results can be considered by parties or government institutions supervising or monitoring the Tallo River estuary.

1. Introduction

Tallo River is a river that divides the city of Makassar with a length of 10 KM, passing through 3 districts/cities, namely Makassar City, Gowa Regency, and Maros Regency, and flowing into the Makassar Strait. The Tallo River estuary area was once the center of the Gowa-Tallo kingdom, with its role as the main trading port in Southeast Asia [1]. Rivers and beaches are interrelated because almost all rivers flow into the coast, so activities carried out along the river basin will affect the coast and vice versa. According to Syarifuddin [2], a river is a large water flow that extends and flows continuously from a higher place to a lower place and flows into the sea, lake, or larger river. River basins with higher current velocities will transport more sediment. When the current velocity decreases, larger sediment particles begin to settle and accumulate on the bottom. The turbulence and sediment distribution interaction can accurately predict sediment transport in coastal environments [3].

Population growth and advancements in science, technology, and knowledge have created opportunities to preserve the sustainability of ecosystems. One of the options for building a megacity and the infrastructure surrounding it will be reclamation [4]. The increase in community activities in the Makassar waters has made the government plan long-term development by utilizing the marine potential through coastal reclamation. Reclamation in developing countries such as Indonesia is being intensively carried out, especially in cities on the coast, to create new residential locations and meet the increasingly limited need for land [5], including building the Makassar New Container Terminal 2. Considering that Makassar is a link for the Eastern Indonesia region, the development of the New Makassar Container Terminal 2 is expected to meet the transportation needs of the community in the area. Reclamation at the New Makassar Container Terminal 2 can be one of the causes of disruption of river flow, so it is necessary to understand the condition of the waters that the existence of coastal reclamation will cause changes in the ecosystem, such as environmental disturbances, erosion, and coastal sedimentation, and changes in current patterns. Changes in current and wave patterns during reclamation construction might result in significant erosion issues [6]. Sedimentation is the process of deposition or formation of sediment. Sedimentation on the coast occurs due to sediment that settles, so it can also disrupt river flow. River shallowing can cause several problems in the sediment transportation process in the estuary, which is very complex, making it difficult to understand the sediment accumulation pattern. Determining the potential impacts of reclamation on the survival of the biota impacted by reclamation and the coastal morphology requires modeling changes in current, the dispersion of suspended sediments, and sea depth. Environmental harm, the loss of wetlands in coastal regions, and the possibility of disasters from coastal flooding brought on by climate change are all consequences of extensive coastal reclamation [7] [8].

The current speed that occurs in the port area of PT. Petrokimia before and after reclamation has changed; the sedimentation rate in existing conditions is 24.015 cm/month, and the sedimentation rate in reclamation conditions is 55.831 cm/month. The difference in sediment volume between existing conditions and after reclamation is 326,869.3 m3 [9].

The current pattern around Segendis Bay has changed before and after reclamation. When conditions are heading towards the highest and lowest tides, the current in Segendis Bay moves towards the open sea. When conditions are at the lowest tide and heading towards high tide, the current moves in the opposite direction. In addition, the current speed at the review point before and after reclamation has changed with a standard deviation ratio of 1.6. The sediment distribution in Segendis Bay Waters in conditions before and after reclamation has changed significantly; the maximum sediment rate in existing conditions is 2.10-7 m3/s/m, and after reclamation is 2.10-8 m3/s/m. The lowest sediment rate is in existing conditions of 1.10-8 m3/s/m, and, after reclamation, is 2.10-8 m3/s/m. This is because the sediment rate that occurs is meager. The most significant bed level change is at review line 2, with an average base change of 0.088 m [10].

According to [11], the current pattern changes around the planned jetty development. The current velocity graph shows the difference between existing and planned jetty development conditions. When conditions are heading towards the highest and lowest tides, the current moves from east to west, from the open sea towards the estuary. When conditions are heading towards the lowest and highest tides, the current moves in the opposite direction, from the estuary towards the open sea. The distribution of sediment in the Tanjung Katimabongko Waters has not changed. The sediment distribution pattern tends to change in the planned jetty development area. Changes in the morphology of the water bed are relatively low. Changes in the morphology of the specified review line support this. On review line 1, erosion occurs, marked by a change of -0.000945 m, sedimentation with a shift in 0.000205 m on review line 2, and on review line 3 of 0.00167 m.

Current changes due to reclamation also occur on the Makassar Coast, as shown by research results [12], show a decrease in current speed of 7.52%. According to [13], the water discharge of the Tallo River reaches a maximum discharge of 79.685 m^3/sec during the rainy season and a minimum discharge of 21.141 m^3/sec during the dry season. The purpose of this study was to determine the current patterns that occur at the Tallo River estuary due to the construction of the New Makassar 2 Container Terminal and to determine the sedimentation patterns that occur at the Tallo River estuary due to the construction of the New Makassar 2 Container Terminal.

2. Methods

The research was conducted in the Makassar City area, precisely in the Mura waters of the Tallo River, located at coordinates 5°5'54.34"S 119°26'53.55"E as shown in Figure 1, using field survey investigation methods, laboratory testing, and analysis using numerical simulation modeling.

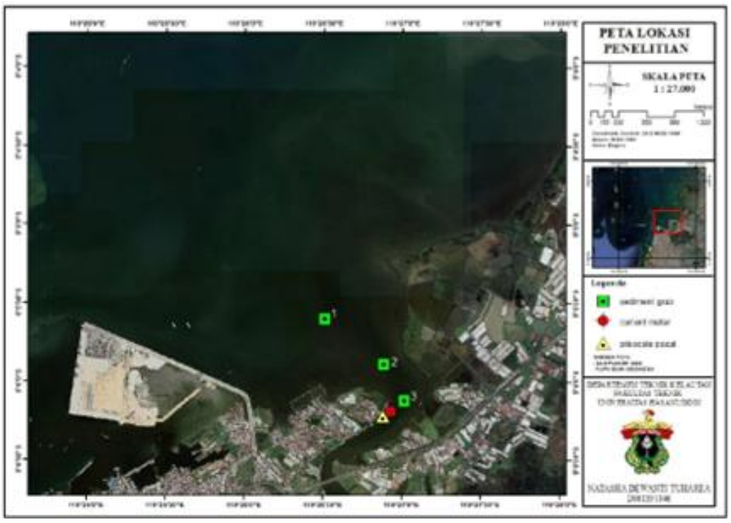

Figure 1. Research Location Map

Field survey activities include bathymetric, current velocity, tidal, and sediment characteristic surveys at the research location. Bathymetric data were obtained from a study conducted for 5 days with a coverage area of approximately 2,350 ha. Bathymetric data is one of the bathymetric contour inputs in the modeling area. From the map, it can be seen that the depth of the Tallo River Estuary waters varies from 0 to 15.9 meters, as shown in Figure 2.

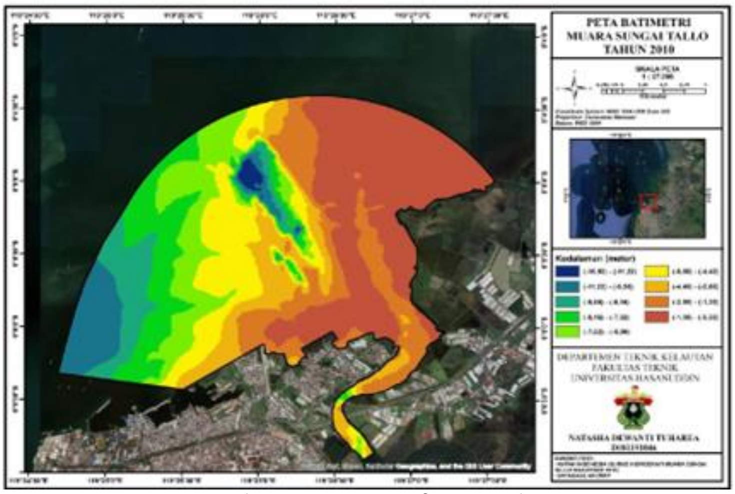

Figure 2. Bathymetric Map of Research Location

Current data taken at the Tallo River Estuary was conducted at points shown in Figure 3 for 25 hours. This data will later validate current data obtained from numerical software forecasting. They will be used to see changes in current patterns around the Tallo River Estuary. Current measurement data was conducted with location points at coordinates 771490.92 m E and 9435419.69 m S. The results of the field survey showed that the lowest current speed was 0.121 m/s and the highest was 0.6139 m/s with the dominant current direction to the southeast.

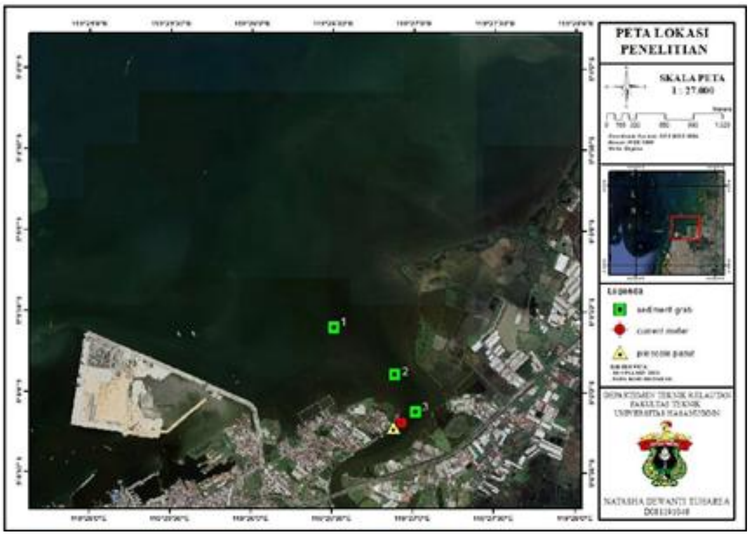

Figure 3. Current Speed Data Collection Location

The tidal data in this study were obtained from direct measurements in the field at coordinates 771,395.85 m E and 9,435,364.15 m S for 15 days with a measurement interval of 1 hour. After processing, the following data were obtained:

1. Highest High Water Level (HHWL) 1.22 m
2. Mean High Water Level (MHWL) 0.96 m
3. Mean Sea Level (MSL) 0.72 m
4. Mean Low Water Level (MLWL) 0.47 m
5. Lowest Low Water Level (MHWL) 0.0 m
6. High Tide 0.51 m
7. Low Tide -0.72 m

The double daily type dominates the Indonesian region's tidal water level movement pattern [14]. The bottom sediment data were obtained from field surveys at three bottom sediment data collection points. Furthermore, sediment size analysis was carried out in the Geotechnical Laboratory. The results showed that the bottom sediment was a type of sand with a D50 diameter of 1.7 mm, 0.75 mm, and 0.22 mm, as shown in Figures 4 to 6.

The wind data used is secondary data obtained from ECMWF Copernicus. The data needed is for 15 days; from ECMWF, the data obtained is 10m u-component of wind and 10m v-component of wind, which are then processed to get the wind direction and speed for the dominant wind direction from the Northwest, and the average wind speed is 3.19 m/sec as shown in Figure 7.

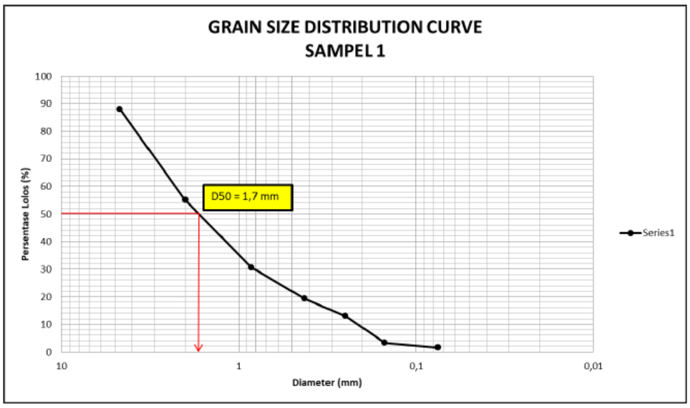

Figure 4. Bottom Sediment Sample Distribution Graph Point 1

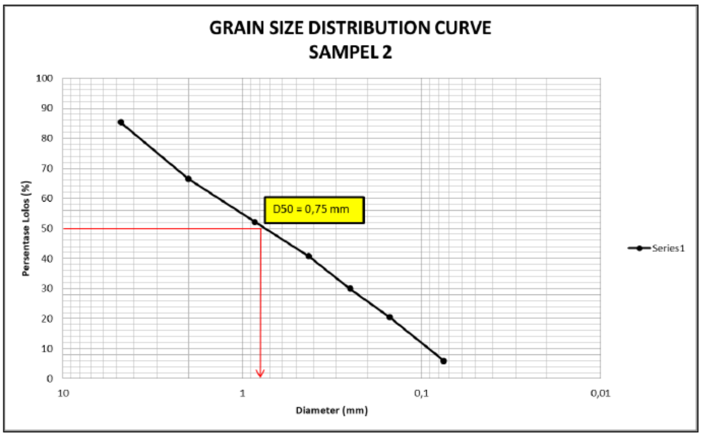

Figure 5. Bottom Sediment Sample Distribution Graph Point 2

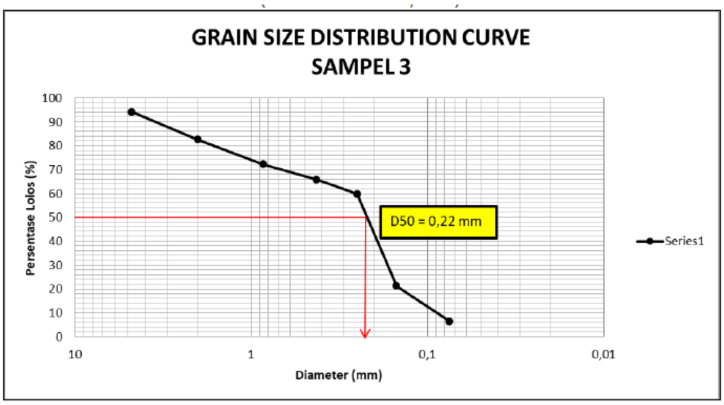

Figure 6. Bottom Sediment Sample Distribution Graph Point 3

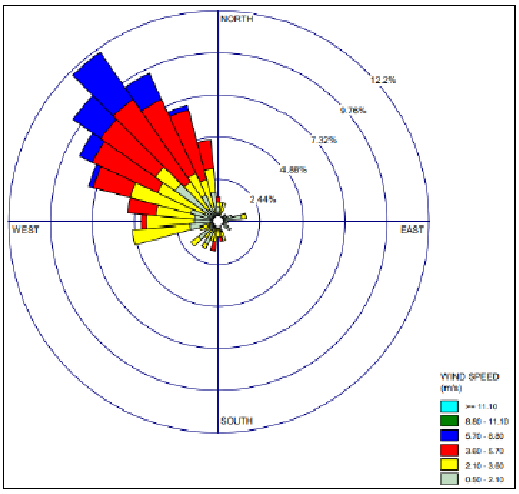

Figure 7. The wind rose of the Tallo River estuary

The numerical modeling study uses software Numerical simulation of hydrodynamic modeling (current) and sediment to determine the sedimentation pattern in the Tallo River Estuary after reclamation. The modeled area is approximately 10363226.6 m2 with a coastline length of 18359.9 m. The land boundary is a boundary line that divides land and sea areas. Land boundary digitization uses software to create lines according to the boundaries of the modeled area as a reference in creating grids and inputting depth data stored in XYZ format, which is to be entered into the numerical simulation as a coastline. The results of land boundary digitization can be seen in Figure 8.

Meshing or griding is the process of dividing the components to be analyzed into small or discrete elements [15]. The better the mesh quality, the higher the convergence rate, so better data will be obtained. The purpose of the meshing grid is to determine the boundaries of land and sea areas. The modeled area is approximately 10363226.6 m2 with a coastline length of 18359.9 m. The results of grid modeling can be seen in Figure 9. Depth data using survey data, namely direct bathymetric measurement data at the Tallo River Estuary. Input bathymetric data using manage scatter data with the format (.xyz), then interpolated into depth data in Figure 10.

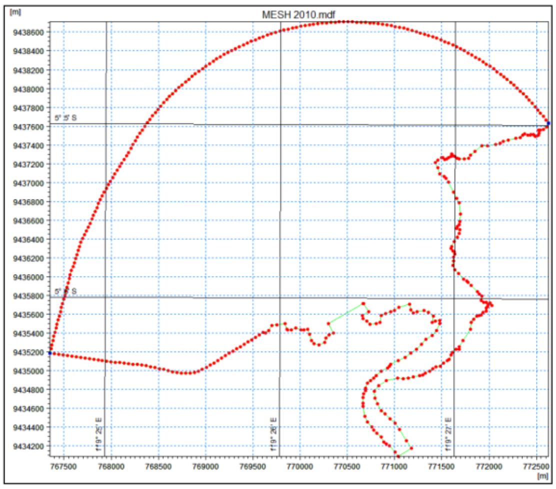

Figure 8. Land Boundary Digitization

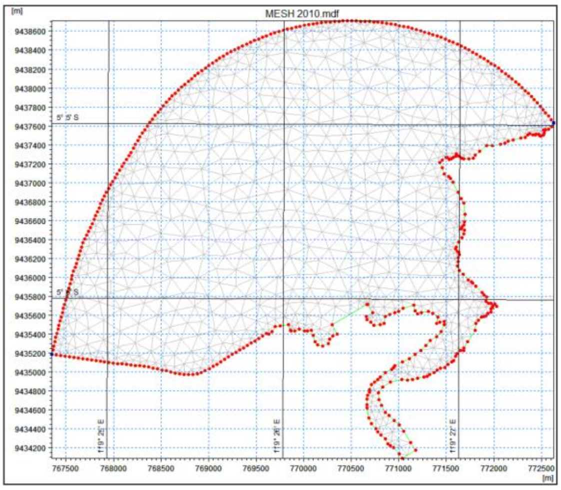

Figure 9. Meshing In Modeling Region

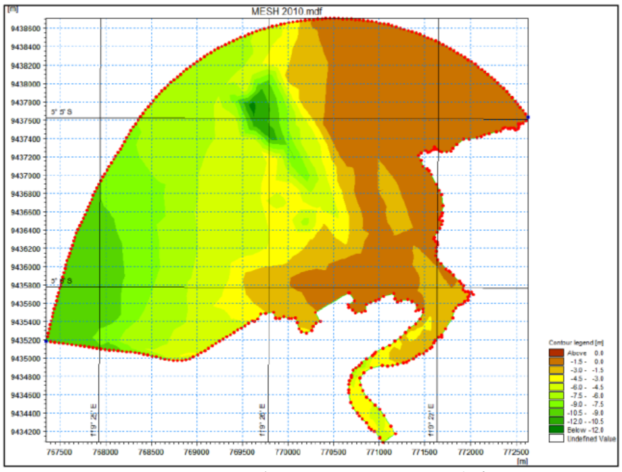

Figure 10. Depth Contours In Modeling Area

In modeling using this numerical simulation, for environmental boundary conditions in hydrodynamic modeling (Hydrodynamic Module) and sand sediment transport modeling (Sand Transport Module) used are bathymetry, tidal, and wind data obtained from field surveys as input to boundary conditions. The following in Table 1, Table 2, and Figure 11 are the environmental boundary conditions used.

Table 1. Hydrodynamic Module Boundary Conditions

Boundary Conditions	**Type**	**Format**	**Input**
Land Boundary (1)	Land (zero average velocity)	-	-
Upstream (2)	Specified (discharge)	Constant	River Discharge Data
Sea Boundary (3)	Specified Level	Varying in time, constant along the boundary	Tidal Data

Table 2. Sand Transport Module Boundary Conditions

Boundary Conditions	**Information**
Upstream (2)	Zero sediment flux gradient
Sea Boundary (3)	Zero sediment flux gradient

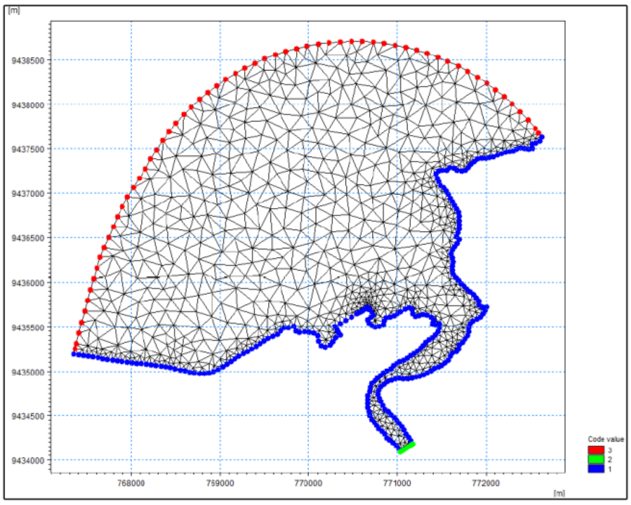

Figure 11. Hydrodynamic Module Modeling Boundary Conditions

Hydrodynamic modeling simulations were conducted in 2 conditions, namely before the construction of the New Makassar 2 Container Terminal and after the construction of the New Makassar 2 Container Terminal, with each model using 359 steps or 15 days. The results of the current pattern simulation in vector form can be seen in Figure 12. Validation is done to compare the simulation results with direct observation data in the field. The validation results are shown in Figure 13.

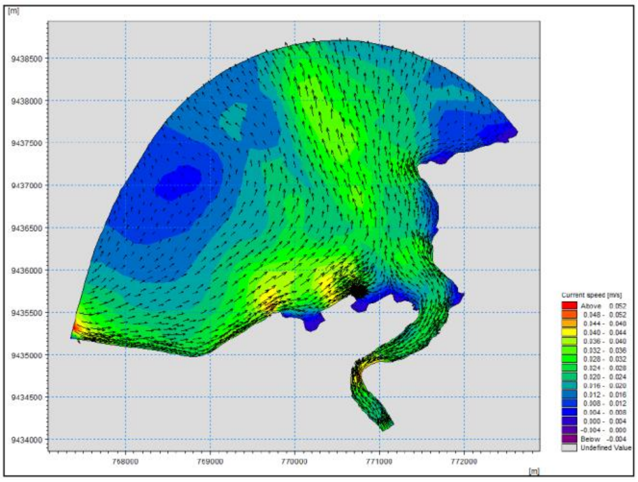

Figure 12. The results of the pattern simulation in vector form

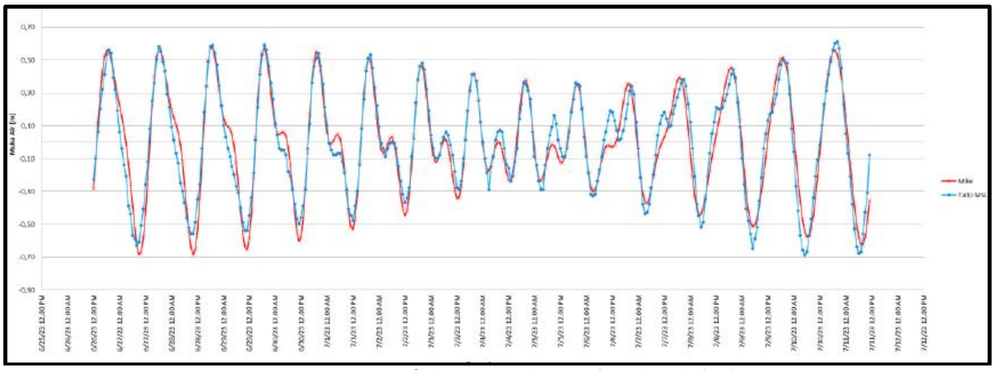

Figure 13. Comparison of direct and simulated tidal observations

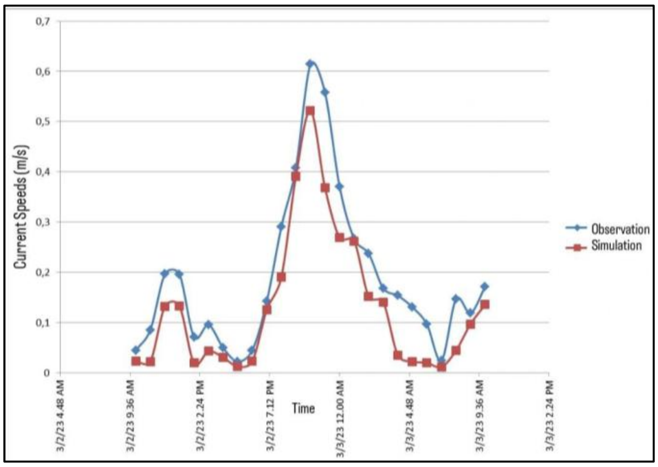

Figure 14. Comparison of direct observation and simulation current speeds

In this study, validation was carried out on the low tide and flow using the RMSE (Root Mean Square Error) method to calculate the amount of the difference between the actual data and the predicted value. The RMSE value obtained was 0.088. Current speed validation was conducted to compare simulation results with direct observation data in the field. The validation results are shown in Figure 14 with a Root Mean Square Error (RMSE) value of 0.0738.

3. Results and Discussion

3.1. Current Pattern before Reclamation

Hydrodynamic modeling simulation at the Tallo River Estuary was carried out for 15 days or 359 time steps after running; the results of the current modeling simulation were obtained in conditions before the construction of the New Makassar Container Terminal 2. Current patterns were observed at the highest and lowest tide conditions, as in Figure 15. The results of the current pattern from the numerical simulation are shown in Figure 16 at the lowest tide at time step 330. The current movement at the lowest tide is from the estuary to the open sea at a speed of around 0.01 – 0.3 m/s. At step 345, when the tide is at its highest, the flow direction is from the open sea to the estuary at a speed of around 0.01 m/s – 0.1 m/s, as shown in Figure 17.

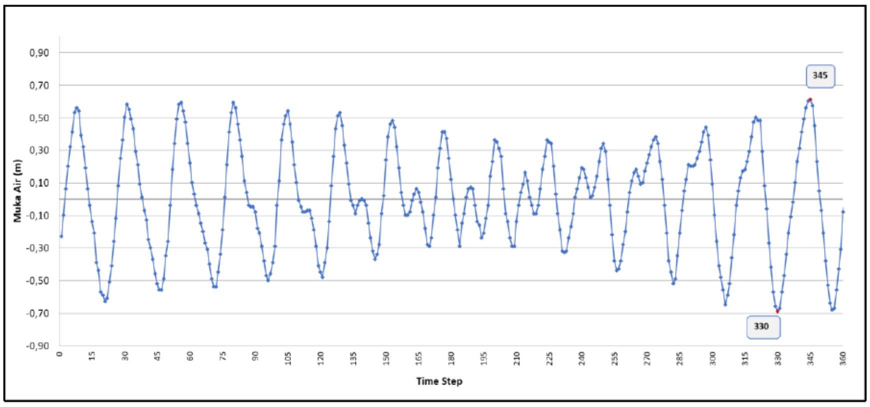

Figure 15. Time Step observation of simulation results

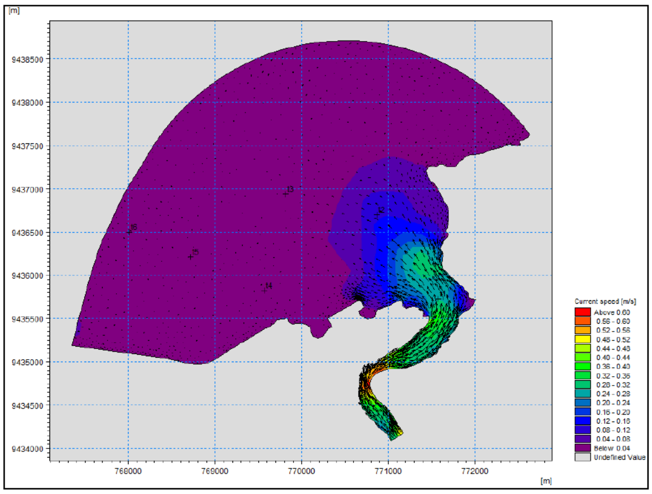

Figure 16. Current pattern during lowest tide (before reclamation)

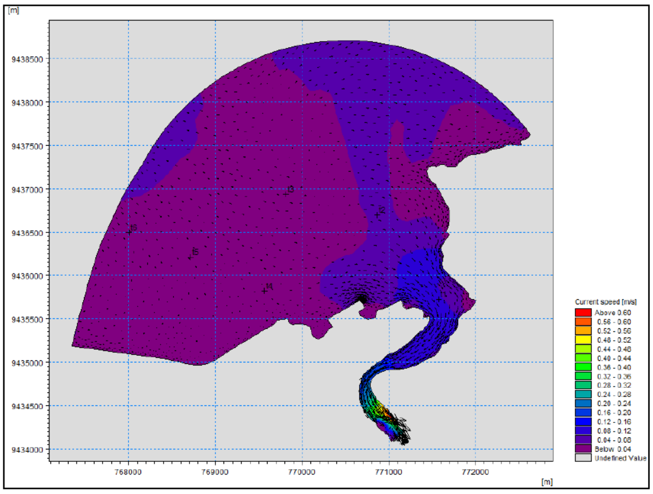

Figure 17. Current pattern during highest tide (before reclamation)

3.2. Current Pattern after Reclamation

Hydrodynamic modeling simulation at the Tallo River Estuary was carried out for 15 days or 359 steps after running; the results of the current modeling simulation were obtained in conditions after the construction of the New Makassar Container Terminal 2. The observations of current patterns at the highest tide conditions showed that the current movement at the lowest tide conditions was a current moving from the estuary to the open sea at a speed of around 0.01 - 0.03 m / s, as shown in Figure 18.

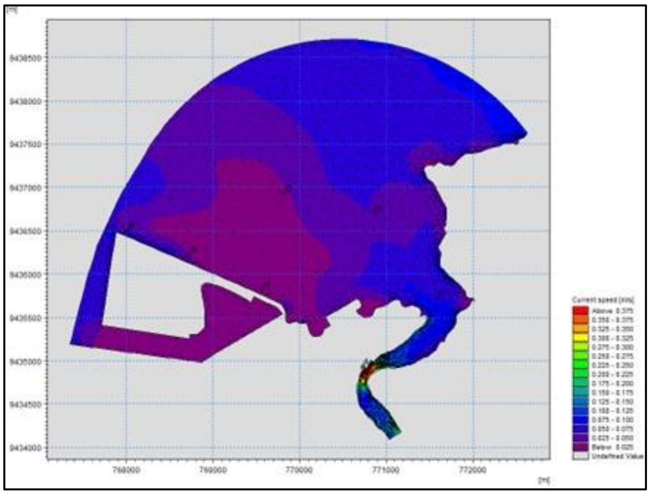
Figure 18. Current pattern during the lowest tide (after reclamation)

At step 345, when the tide is at its highest, the flow direction is from the open sea to the estuary at a speed of around 0.007 m/s – 0.015 m/s, as shown in Figure 19. According to previous research analysis, the current pattern at the highest tide for conditions after reclamation can be observed, which moves from the open sea to the coast. This pattern is different from the existing conditions because of the reclamation itself. The form of reclamation causes a change in the pattern. From the current pattern at the lowest tide for conditions after reclamation, it can be observed that the current pattern moves from the coast to the open sea. This phenomenon occurred at 18.00 WIB on July 21, 2016 [16].

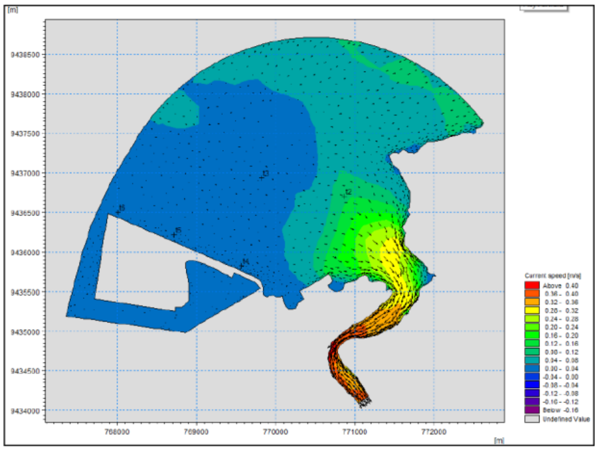

Figure 19. Current pattern during the highest tide (after reclamation)

After 15 days of hydrodynamic modeling in conditions before and after the construction of the New Makassar 2 Container Terminal, it can be observed that there is a change in current speed in both models. These changes can be seen in Table 3, which compares current speeds in conditions before and after the construction of the New Makassar 2 Container Terminal at the highest tide, the current pattern in conditions before and after construction changes; namely, the current moves from the river mouth to the open sea, but with a current speed after reclamation that is smaller than before construction. When approaching low tide, the current pattern changes with the direction of the current towards the river mouth. Based on the results of the current pattern analysis, it can be seen that reclamation affects the current pattern, as also shown in [17] In the 1995 simulation, the flow velocity ranged from 0 to 1.4 m/sec. The 2016 simulation's flow velocity ranged from 0 to 1.35 m/sec. When the reclamation was carried out, the flow velocity ranged from 0 to 1.2 m/sec, and it was found that during low tide conditions, several areas in the bay were not submerged in water due to the high rate of sedimentation and unstable sediment distribution caused by the construction of Benoa Bay.

Table 3. Comparison of Current Speeds

Point of View	Longshore Current (m/sec)			
	Before Reclamation		After Reclamation	
	High tide	Low tide	High tide	Low tide
1	0.132	0.177	0.128	0.018
2	0.377	0.068	0.087	0.022
3	0.138	0.034	0.028	0.019
4	0.132	0.022	0.021	0.019
5	0.081	0.031	0.018	0.026
6	0.059	0.018	0.019	0.032

3.3. Sedimentation Pattern before Reclamation

A sediment transport simulation was conducted to determine the sediment distribution pattern due to the influence of current speed and direction in the previous hydrodynamic simulation. From the simulation results, sediment distribution is influenced by the current pattern generated by the low tide and flow. When viewed at the highest tide in Figure 20, it shows that the current moves from the open sea to the river mouth; the sediment rate condition at the Tallo River Estuary is 0-0.035 m^3/sec/m.

Meanwhile, at the lowest tide in Figure 21, the current moves from the estuary to the open sea with a sediment rate in the Tallo River Estuary of 0-0.0065 $m3/\text{sec}/m$. This aligns with the research results [18], which state that the sediment concentration around the Cisadane River estuary is relatively high and can move far toward the sea when the tide is compared to the high tide. This is because when the high tide is approaching the low tide, the mass of water entering the river will be pushed back by the mass of river water carrying sediment material from the mainland towards the sea [19].

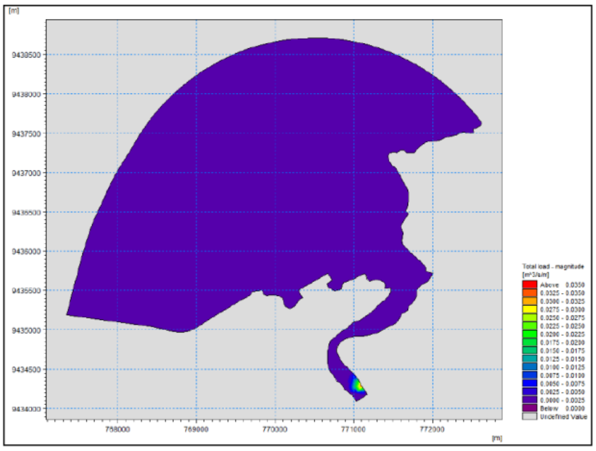

Figure 20. Sediment distribution pattern during highest tide conditions (before reclamation)

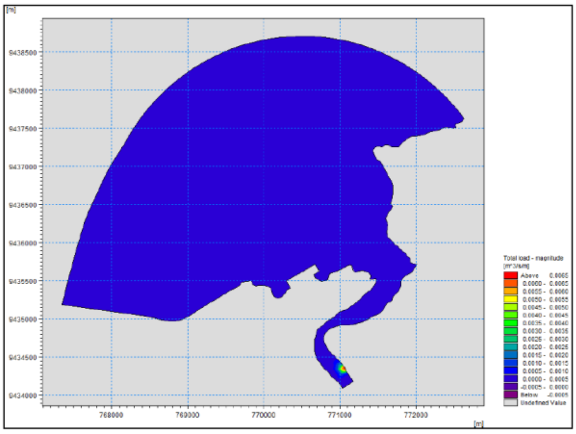

Figure 21. Sediment distribution pattern during lowest tide conditions (before reclamation)

3.4. Sedimentation Pattern after Reclamation

After simulating the sediment distribution pattern before constructing the New Makassar 2 Container Terminal, the next step is to simulate the conditions after creating the New Makassar 2 Container Terminal. From the simulation results, the sediment distribution is influenced by the current pattern generated by the low tide and flow. At the highest tide conditions, the current moves from the open sea to the river mouth, and the sediment rate condition at the Tallo River Estuary is 0.002–0.030 $m^2/s/m$. Meanwhile, at the lowest tide, the current moves from the estuary to the open sea with a sediment rate at the Tallo River Estuary of 0-0.0009 $m^3/s/m$.

After the simulation and modeling results of the sedimentation pattern in the conditions before and after the construction of the New Makassar 2 Container Terminal, changes in the pattern can be analyzed so that it can be known how the influence that occurs due to the construction of the New Makassar 2 Container Terminal from the parameters of changes in the sediment pattern in the waters of the Tallo River Estuary. When the tide conditions are highest in Figure 22, the sediment distribution pattern does not change significantly with the sediment rate in the conditions before construction of 0-0.035 $m^3/s/m$ and after construction of 0-0.030 $m^3/$ s/m. Figure 23 shows the distribution pattern at the lowest tide, where the sediment distribution pattern changes slightly. In post-development conditions, the sedimentation rate around the estuary area increased from 0-0.0065 $m^3/s/m$ to 0-0.0009 $m^3/s/m$.

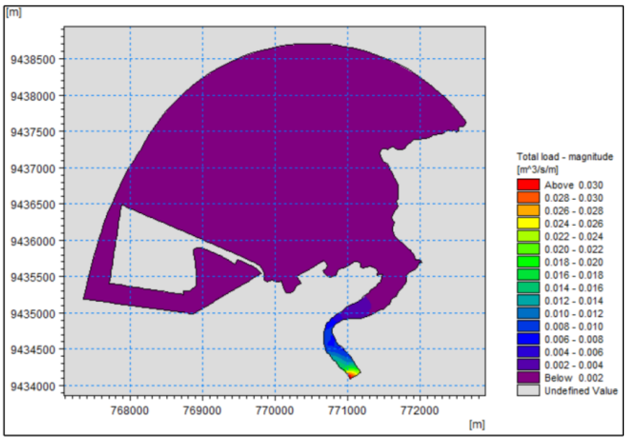

Figure 22. Sediment distribution pattern during the highest tide conditions (after reclamation)

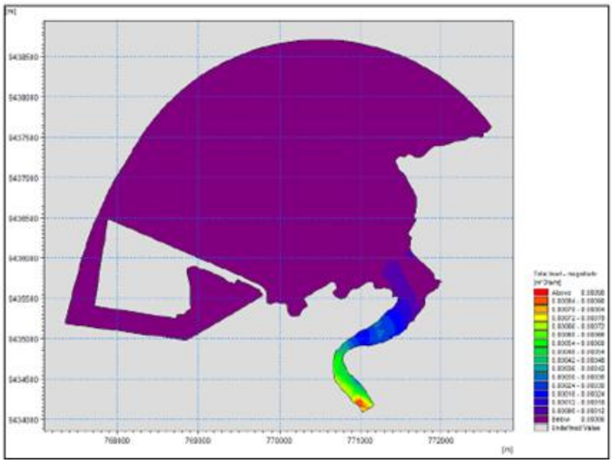

Figure 23. Sediment distribution pattern during the lowest tide conditions (after reclamation)

3.5. Changes in the Morphology of the Water Base of the Tallo River Estuary

Changes in the morphology of the water bed will occur when there is a sediment transport process in the water. A review was conducted at a predetermined point to see the changes in the bed morphology in the Tallo River Estuary waters, as shown in Figure 24. After determining the location of the review line, the difference in the base surface or bed level that occurs due to sediment transport that appears in the waters of the Tallo River Estuary before and after the construction of the New Makassar 2 Container Terminal will be seen, which is obtained after extracting the sedimentation pattern data that has been made and then presented in the form of a graph showing that there is a significant change in the morphology of the seabed. The depth of the waters tends to change upwards; this means that the waters become shallower due to sedimentation. There is a change in the seabed that occurs from the conditions before and after the construction of the New Makassar 2 Container Terminal, which is reviewed on line 1 with an average of 0.055 m, indicating that there is shallowing due to sedimentation.

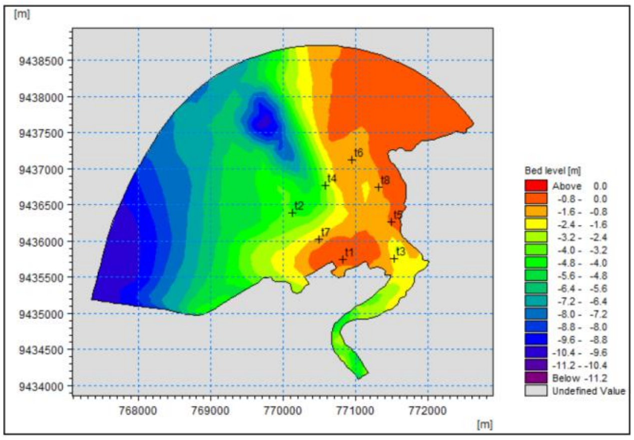

Figure 24. Location of survey lines for changes in the morphology of the Tallo River Estuary

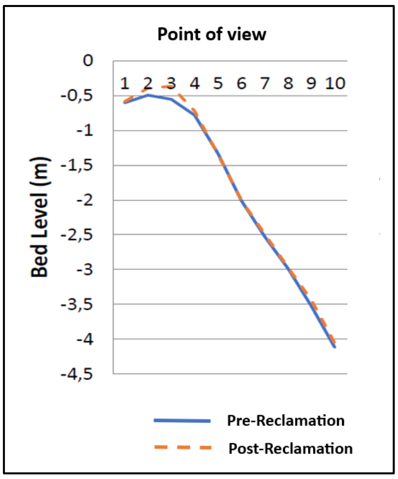

Figure 25. Morphological changes in review line 1

Similar to the conditions reviewed on line 1 in Figure 25, there was a change in the seabed from the conditions before and after the construction of the New Makassar 2 Container Terminal reviewed on line 2 (Figure 26) with an average of 0.096 m, indicating that there was shallowing due to sedimentation. Meanwhile, on review line 3, as shown in Figure 27, there was a change in the seabed conditions before and after the construction of the New Makassar 2 Container Terminal, with an average change in the bottom morphology of 0.048 m, which indicates that there was shallowing due to sedimentation.

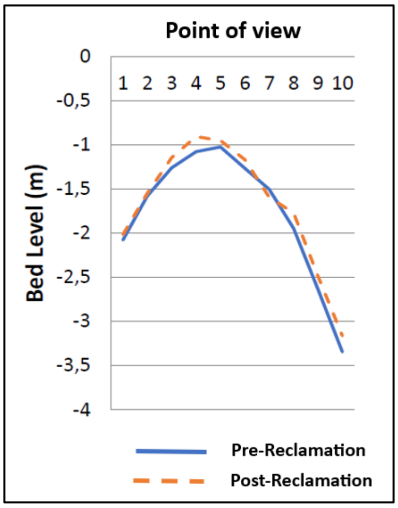

Figure 26. Morphological changes in review line 2

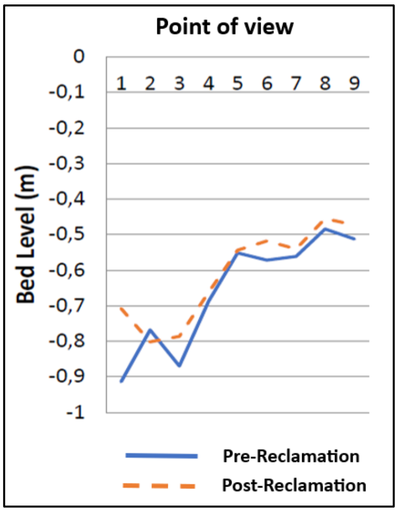

Figure 27. Morphological changes in review line 3

The most considerable seabed changes occurred at line 4, as shown in Figure 28, from the conditions before and after the construction of the New Makassar 2 Container Terminal, with an average change of 0.158 m, indicating that shallowing occurred due to sedimentation. On line 5, as shown in Figure 29, changes in the seabed that occurred from conditions before and after the construction of the New Makassar 2 Container Terminal were, on average, 0.059 m, indicating that there was shallowing due to sedimentation.

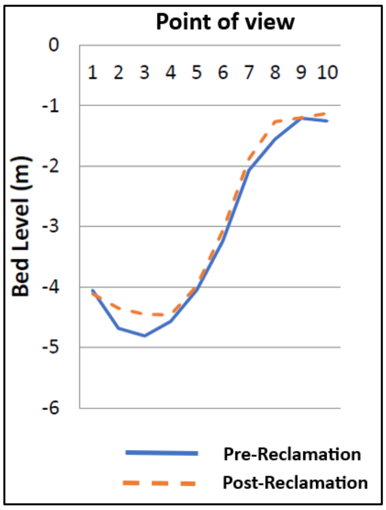

Figure 28. Morphological changes in review line 4

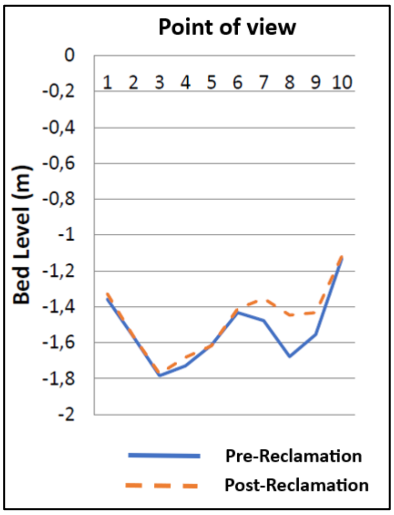

Figure 29. Morphological changes in review line 5

It can be seen from the graphic image that significant changes have been made in the morphology of the water bed/bed level. The depth of the water after the construction of the New Makassar 2 Container Terminal has become shallower; this means that the water bed has become shallower due to sedimentation. The results of previous research at Teluk Lamong Port reinforce this. The morphology, including the coastline and coastal processes at Teluk Lamongan Port, has also undergone quite significant changes due to the impact of changes in land use and land use from the construction of Teluk Lamongan Port. Changes in the coastline, in 2012 and 2020 Teluk Lamong Port has experienced sedimentation at coordinates 7 ° 10'50.4 "S 112 ° 40'33.3" E with a length of coastline change reaching 950 m and sedimentation in the Karang Kiring Coastal area at coordinates 7 ° 11'14.7 "S 112 ° 39'56.8" E reaching 480 m. Galang Island at coordinates 7°11'38.7"S 112°39'57.0" E from 2012 to 2020 experienced a change in coastline of up to 430 m [20].

4. Conclusion

The current pattern that exists in the area surrounding the Tallo River Estuary before and after the construction of the New Makassar 2 Container Terminal has decreased by an average of 51.28% from 0.105 m/s -0.051 m/s, according to the results of numerical simulations of current pattern modeling and sediment patterns in conditions before and after reclamation. The current flows from the open sea into the estuary during the highest tide. The current shifts from the estuary to the open sea during the lowest tide.

The distribution of sediment in the Tallo River Estuary waters has changed from the conditions before and after the construction of the New Makassar 2 Container Terminal, which causes changes in the basic morphology of the Tallo River Estuary waters, which tend to be high. This is evidenced by changes in morphology at the specified review lines. At review lines one to five, sedimentation occurs, marked by successive changes of 0.055 m, 0.096 m, 0.048 m, 0.158 m, and 0.059 m. Recommendations for further research development are to vary the input values so that the accuracy of the modeling can be increased. The Spectral Wave module must also define waves according to natural conditions.

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