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Tidal Current Pattern Modeling in the Wain River Shipping Channel Waters

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KEYWORDS
Tidal Currents
Current
Modeling Current
Patterns

ABSTRACT – Semi-enclosed waters surrounded by islands such as Balikpapan Bay, whose waters are influenced by the dynamics of sea tides which affect current speed. Therefore, to understand the pattern and circulation of ocean currents in Balikpapan Bay, especially in the Wain River shipping channel, one way is by hydrodynamic modeling. The water area on the Wain River is an area related to shipping lanes as a shipping route at the Ferry Port. This research on current speed and direction aims to further research on maintaining the depth of shipping lanes due to sedimentation around the Ferry Harbor waters. Therefore, researchers conducted an initial study to create a simulation model of tidal current patterns using Mike 21 software with the aim of finding out what the tidal current patterns and current directions are in the waters of Balikpapan Bay as further data for maintaining the depth of shipping lanes. The data processing used is based on primary data in the form of current speed and direction, and tides and secondary data in the form of depth, current speed and direction, and tides, which are then validated using the RMSE method and to determine the type of tide using the Almilarty method. The results of this research are modeling tidal flow patterns and mapping changes in the morphology of the Wain River. The current speed at high tide ranges from 0.1 m/s to 0.4 m/s, while the current speed at low tide ranges from 0.1 m/s to 0.2 m/s. The depth of the waters around the Wain River is 1 m to 5 m. The tidal type in the waters of the Wain River is a mixed daily double bias.

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INTRODUCTION

Indonesia is an archipelagic country with extensive coastal areas. Coastal areas serve as land protection from natural phenomena originating from the sea. Furthermore, coastal areas are a crucial factor in infrastructure development and community activities. Numerous coastal features influence physical and biological processes, including the shape of bays. A bay is a semi-enclosed body of water surrounded by islands. One such channel is a shipping lane that supports economic development as a maritime transportation route. The Wain River, including the Wain River, is a region with development potential in

Kalimantan, particularly East Kalimantan (Bappeda Balikpapan City, 2007). This potential requires development and maintenance to preserve nature and maximize existing infrastructure. Monitoring coastal dynamics is used for infrastructure development and preservation, such as monitoring current patterns, water depth, tides, and wave heights. For example, in the Wain River, continuous monitoring of tidal patterns is necessary. Tides are the periodic rise and fall of sea levels due to tidal forces, primarily derived from the gravitational forces of astronomical objects, namely the moon and the sun. Tides can influence current patterns. Over time, these regular current patterns in waters will affect the distribution of sedimentation on the seabed, resulting in changes in water depth.

Therefore, a study using tidal current simulation modeling using Mike 21 software is necessary. The researchers formulated the problem based on tidal current patterns, speed, and direction of the Wain River currents in order to determine the tidal current simulation patterns, speed, and direction of currents as initial material for maintenance studies on the Wain River shipping channel.

METHODS

Research Overview

This study aims to determine the current pattern of the Wain River waters in the Wain River as a study of water depth maintenance using the Mike 21 software. The research location is located between 116° 42' - 116° 50' East Longitude and 1° - 1° 22' South Latitude attached in **Figure 1** (left). Before this study was conducted, researchers made points on the Wain River shipping route using Google Earth to see a general overview of the area in **Figure 1** (right) and accompanied by references to the literature study of the location. After determining the point, a field survey was conducted by determining the point using GPS, the data taken were, current speed data, current direction, tides, and depth data. Current speed and direction data used a current meter, tidal data used a tide gauge, and depth data used an aquamap. The results to be carried out include making a map and modeling the speed and direction of the Wain River waters as data for the depth maintenance study of the area.

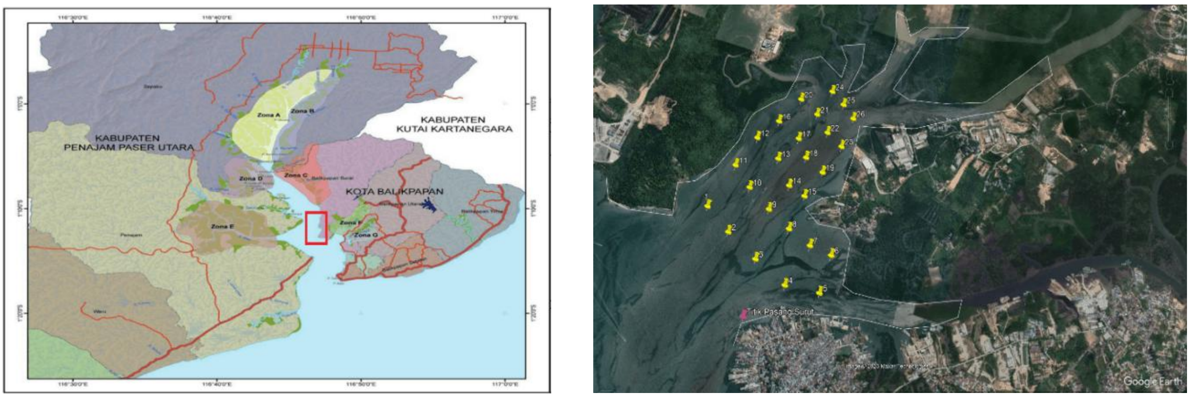

Figure 1. Research Location (left) Tidal and Bathymetric Data Collection Point (right)

Data And Equipment

The data used in this study include:

1. Bathymetric data for the Wain River waters comes from Navionic.
2. Wain River coastline data created based on Google Earth in **Figure 2** (left) as the boundary between the sea and land. Wain River tidal data at one point in **Figure 3** (left) as modeling material for Mike software based on field surveys, before modeling is carried out, a bathymetric mesh and coastline will be created in **Figure 2** (right) then interpolated and smoothed the mesh in **Figure 3** (right). Current speed and direction data are based on field surveys using a current meter. Depth data are based on field surveys using an Aquamap measuring tool.

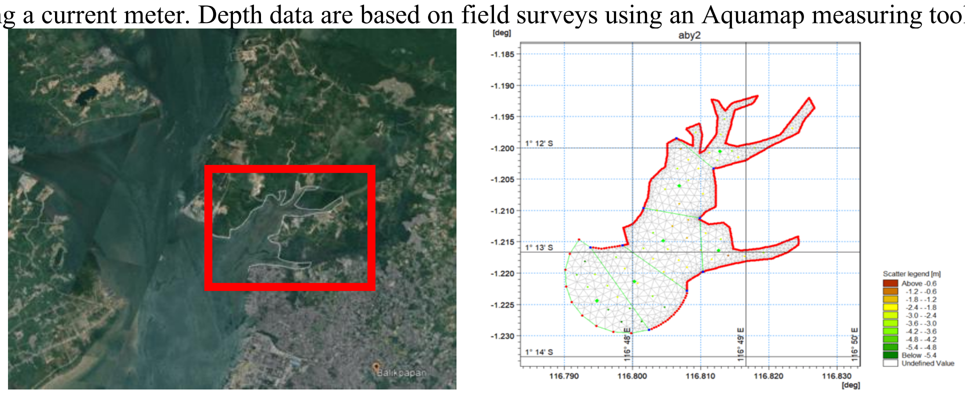

Figure 2. Sea Boundaries and Coastlines (left) and Coastline Mesh and Bathymetry (right)

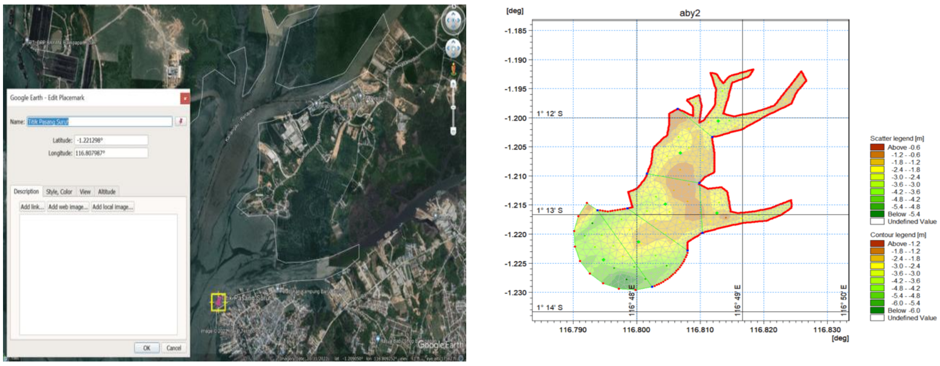

Figure 3. Tidal Data Collection Points (left) and Interpolate Mesh (right)

3. Tide data is obtained based on data storage from Tides.BIG (Geographic Information Agency) as modeling data that will be validated with field survey tidal data in **Table 1**.

Table 1. Tidal Field Survey (June 10, 2022)

Time	Elevation	Time	Elevation
11.00	0.322174	01.00	0.685174
12.00	0.322174	02.00	0.353174
13.00	0.0991738	03.00	-0.00582625
14.00	-0.190826	04.00	-0.321826
15.00	-0.445826	05.00	-0.499826
16.00	-0.569826	06.00	-0.526826
17.00	-0.523826	07.00	-0.428826
18.00	-0.344826	08.00	-0.237826
19.00	-0.0808262	09.00	-0.00582625
20.00	0.229174	10.00	0.227174
21.00	0.526174	11.00	0.400174
22.00	0.766174		
23.00	0.903174		
24.00	0.887174		

4. The equipment used in this research includes:

- GPS to determine research location points and research sampling points (using aquamap plot).
- Current meter for collecting data on current speed and direction based on the depth data collection point. The field survey data are shown in **Table 2** below.
- Tide gauge for collecting tidal data. The results of the tidal field survey are shown in Table 1.
- Boats for transportation on the Wain River.

Table 2. Current Velocity Field Survey Data

Point	Current Speed (m/s)	Current Direction	Point	Current Speed (m/s)	Current Direction	Point	Current Speed (m/s)	Current Direction
1	0,2	BL 329	11	0,21	T 108	21	0,2	TG 137
	0,1	U 355		0,21	TL 55		0,1	BL 328
	0,2	T 71		0,21	T 108		0,2	TL 60
2	0,2	B 269	12	0,1	TL 25	22	0,1	B 253
	0,2	BD 237		0,1	BL 326		0,1	TG 128
	0,1	T 103		0,1	U 357		0,1	S 167
3	0,1	TG 12	13	0,2	T 92	23	0,2	TG 137

Point	Current Speed (m/s)	Current Direction	Point	Current Speed (m/s)	Current Direction	Point	Current Speed (m/s)	Current Direction
	0,1	BL 297		0,2	TL 28		0,1	BL 328
	0,1	TL 40		0,1	U 8		0,2	TL 60
4	0,1	B 269	14	0,1	BD 236	24	0,1	BD 236
	0,1	BD 237		0,1	U 357		0,1	B 249
	0,1	TL 59		0,1	BL 337		0,1	BD 229
5	0,1	BD 222	15	0,13	BL 30	25	0,3	BD 205
	0	TL 46		0,2	T 78		0,3	BD 237
	0,2	U 355		0,2	B 262		0,3	T 87
6	0	BD 241	16	0,1	T 76	26	0,3	TG 143
	0,2	BP 233		0,1	B 250		0,1	T 83
	0,1	BD 205		0,1	T 102		0	BD 229
7	0	BL 315	17	0,3	T 92			
	0	TL 29		0,2	T 95			
	0,1	S 158		0,3	BL 239			
8	0,2	U 12	18	0,1	T 90			
	0,1	T 69		0,1	U 364			
	0,1	BL 336		0,1	TL 24			
9	0,13	TL 40	19	0,2	BL 329			
	0,1	T 88		0,2	BL 309			
	0,1	T 91		0,15	T 72			
10	0,1	T 111	20	0,1	B 253			
	0,1	U 345		0,1	TG 128			
	0,1	T 46		0,1	S 167			

RESULTS AND DISCUSSION

Tidal Type Classification

Calculations using the Admiralty method are used to find the amplitude (A) and phase difference (g^0) values from 15 observation days and the corrected mean sea level (S_0). The following are the tidal components analyzed using the Admiralty method in June 2023.

Table 3. Tidal Components in 2023

	Tidal Component Results									
	S0	**M2**	**S2**	**N2**	**K1**	**O1**	**M4**	**MS4**	**K2**	**P1**
A Cm	0.000	0.259	0.181	0.086	0.331	0.256	0.002	0.002	0.049	0.109
g^o		282.07	179.70	30.07	104.52	67.42	147.06	282.48	179.70	104.52

The tidal types in the Madura Strait waters in 2023 according to the Formzahl number (F) based on the tidal components in the table above. The Formzahl numbers are 1.336 and 1.433, based on **Table 4**, these numbers are classified as 0.25 < F < 1.5 or a mixed double daily skew.

Tidal Elevation Verification

Comparison of observed and predicted tidal data showed strong agreement, with RMSE = 0.253 and CF = 0.485, indicating excellent validation (CF < 1).

$$F = (K1+O1) / (M2+S2) \quad (1)$$

$$= (0.331+0.256) / (0.259+0.181)$$

= 1.336

Table 4. Types Of Tides

Value	Type of Tide	Phenomenon
0 < F <0.25	Double daily	2X pairs a day with relatively the same height
0.25 < F < 1.5	Daily leaning mix	2X pairs a day with different height differences and intervals
1.5 < F < 3	Single daily skew mix	1x or 2x pairs a day with different intervals
F > 3	Single	1x pair a day, during spring it occurs 2x pairs a day

Tidal Data Verification

The 2012 Tidal Analysis was used as a reference for data verification in June 2023. Quantitatively, by calculating the magnitude of the error that occurred from each data, it can be calculated as follows:

$$\boldsymbol{RMSE} = \left(\frac{\boldsymbol{\Sigma(y_i - \hat{y}_i)}}{\boldsymbol{n}}\right)^{1/2} \quad (2)$$

where:
RMSE : *Root Mean Square Error*
y : Secondary data June 2023
ŷ : primary data June 2023
n : Amount of data

Based on the results of the tidal analysis and verification, the **RMSE value was 0.253**, or a **99.747%** confidence level. Model verification was used to quantitatively determine the accuracy of the two wind data sources by calculating the error in each data point. Wind speed verification used Cost Function (CF) statistical analysis. According to George et al. (2010), the CF method can be calculated using the following formula:

$$\text{CF} = \frac{1}{N}\sum_{n=1}^{N}\frac{|Dn - Mn|}{\sigma D}$$

with,

$$\boldsymbol{\sigma D} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(\boldsymbol{Dn} - \boldsymbol{\bar{D}})^2}$$

where:
N : Amount of data
n : Data to n
D : 2012 data values
$\boldsymbol{\sigma D}$ **:** Standard deviation
M : Secondary data value 2023
$\boldsymbol{\bar{D}}$: Primary data 2023 average
CF : *Cost Function*

Menurut George *et al.* (2010), kriteria yang digunakan adalah

CF < 1	=	Very Good	1 < CF < 2	=	Good
2 < CF < 3	=	Less	CF > 3	=	Very Poor

Based on the analysis, the CF obtained was 0.485. This means that the data verification for 2012 and 2020 fell within the **CF <1** range, indicating **Very Good**.

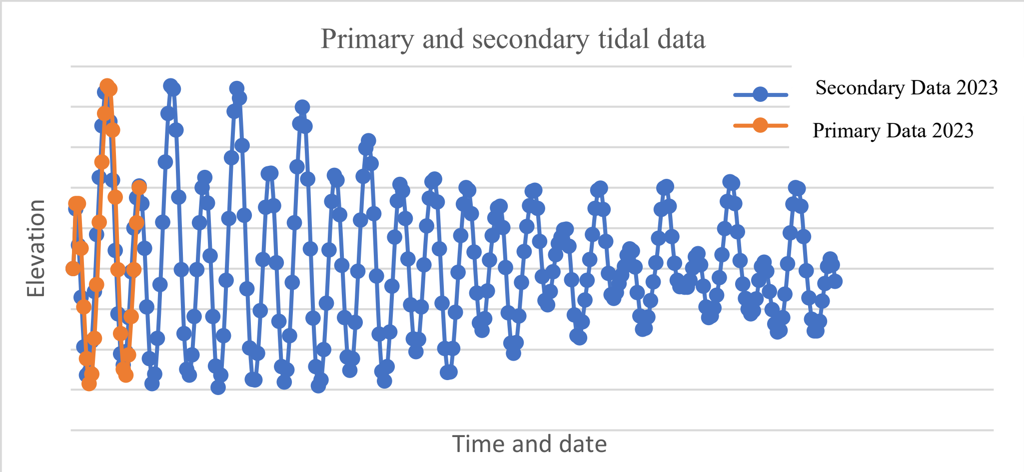

Figure 4. Verification of Primary and Secondary Tidal Data

Depth Profile Verification

The following data shows the water depth of the Wain River based on Navionic and GEBCO data. By comparing the primary data collection with the secondary data coordinates, which are bolted to the primary data collection points in the field, several secondary data points differ significantly from the primary data collected in the field, as seen in **Figure 5**. The water depth of the Wain River, based on 26 points, is shown in **Table 6**, with a depth variation of 1 m to 5 m.

Table 5. Secondary Depth Data

No	X	y	Z	No	X	y	Z	No	X	y	Z
1	**116.7931**	**-1.2181**	**-5.4409**	**21**	**116.8031**	**-1.21354**	**-3.9642**	41	116.807	-1.2001	-1.3785
2	**116.7945**	**-1.2202**	**-3.5178**	22	116.8052	-1.2162	-2.6786	42	116.8082	-1.2018	-2.3479
3	**116.7963**	**-1.2220**	**-3.2340**	**23**	**116.8068**	**-1.21792**	**-1.8322**	**43**	**116.8097**	**-1.203**	**-2.0068**
4	**116.7978**	**-1.2238**	**-2.8125**	**24**	**116.808**	**-1.21906**	**-2.1285**	44	116.8113	-1.2007	-2.8895
5	116.7996	-1.2256	-4.4179	25	116.8036	-1.21002	-2.0285	45	116.8125	-1.2019	-3.4591
6	**116.8013**	**-1.2277**	**-5.3863**	26	116.8058	-1.21249	-1.3010	46	116.8146	-1.2005	-3.6733
7	116.7918	-1.2203	-4.3826	**27**	**116.808**	**-1.2144**	**-1.6758**	47	116.8155	-1.2015	-2.2722
8	116.7934	-1.2222	-4.0137	**28**	**116.81**	**-1.2163**	**-1.4119**	**48**	**116.8179**	**-1.2000**	**-2.8007**
9	116.7949	-1.2242	-4.7403	**29**	**116.8116**	**-1.21782**	**-2.1254**	49	**116.8234**	**-1.1968**	**-1.923**
10	116.7965	-1.2258	-4.8570	30	116.814	-1.21716	-1.09	**50**	**116.8129**	**-1.1978**	**-2.5205**
11	116.7984	-1.2278	-6.8318	31	116.813	-1.21459	-3.0225	**51**	**116.8135**	**-1.1953**	**-3.4795**
12	**116.7976**	**-1.2174**	**-3.9124**	32	116.8164	-1.21734	-2.342	**52**	**116.8093**	**-1.1975**	**-2.9935**
13	**116.7989**	**-1.2192**	**-2.4779**	**33**	**116.8192**	**-1.21669**	**-3.5421**				
14	**116.8008**	**-1.2216**	**-1.9778**	34	116.8107	-1.21365	-2.002				
15	**116.803**	**-1.2237**	**-3.9863**	35	116.8082	-1.21151	-0.6314				
16	**116.8047**	**-1.2254**	**-4.9707**	36	116.8069	-1.20895	-0.2937				
17	**116.8016**	**-1.2160**	**-3.072**	37	116.8048	-1.20658	-2.6163				
18	**116.8031**	**-1.2173**	**-2.2633**	**38**	**116.8066**	**-1.2033**	**-3.4018**				
19	**116.8046**	**-1.2198**	**-2.1902**	39	116.8082	-1.20521	-2.5				
20	**116.8058**	**-1.2216**	**-1.8158**	40	116.8104	-1.20735	-2.1201				

Table 6. Primary Depth Data

Point	x	y	z	Point	x	y	z
1	116.7978	-1.22381	-1,6	16	116.8058	-1.2210	-1
2	116.7931	-1.21810	-4,1	17	116.7976	-1.2174	-3,6

Point	x	y	z	Point	x	y	z
3	116.8068	-1.21791	-1,1	18	116.8008	-1.2216	-1,1
4	116.7963	-1.22201	-4,8	19	116.7989	-1.2192	-2,6
5	116.808	-1.21439	-1,1	20	116.8031	-1.2177	-3,9
6	116.81	-1.21629	-3,6	21	116.808	-1.2190	-2,8
7	116.8046	-1.21982	-2,7	22	116.813	-1.2145	-4,8
8	116.8013	-1.22772	-5	23	116.8066	-1.2033	-1,6
9	116.7945	-1.22020	-2,3	24	116.8097	-1.203	-1
10	116.81	-1.21629	-1	25	116.8179	-1.2000	-2,3
11	116.8116	-1.21782	-2,3	26	116.8093	-1.1975	-1
12	116.8192	-1.21668	-3,1				
13	116.8047	-1.22543	-2				
14	116.8016	-1.21601	-3				
15	116.803	-1.22372	-3,3				

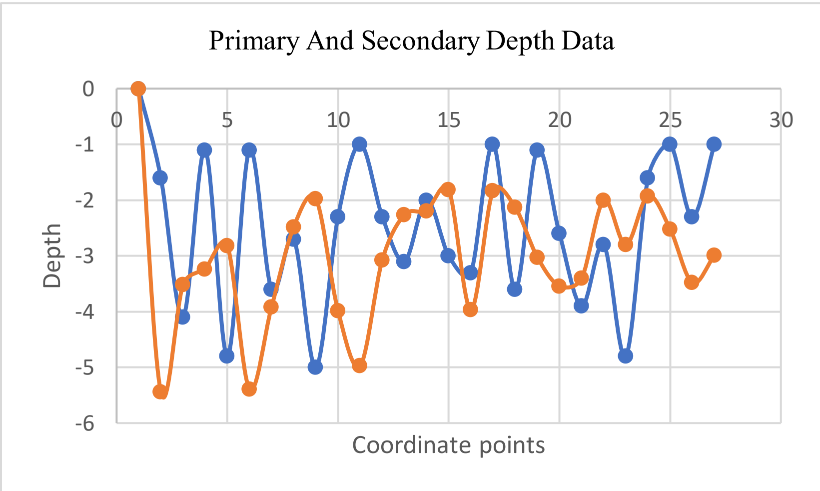

Figure 5. Comparison of Primary and Secondary Depth Data

Hydrodynamic Simulation

Based on the Wain River current modeling, data obtained during the highest tide with a speed of 2 m/s – 5 m/s, while data during low tide with a speed of 0.05 m/s – 3 m/s is shown in Table 7. The current pattern model at the lowest low tide, as seen in Figure 9 (left), occurred on June 5, 2023, at 7:00 PM, with a water level at low tide of -0.00582625 meters at coordinates 116.8046; -1.21982, and the current direction at low tide towards Balikpapan Bay. The water level at high tide was 0.903174 meters at coordinates 116.813; -1.2190, with a speed of around 0.3 m/s. Based on the image, it can be seen that during high tide the current flows from Balikpapan Bay towards the Wain River in **Figure 6** (right).

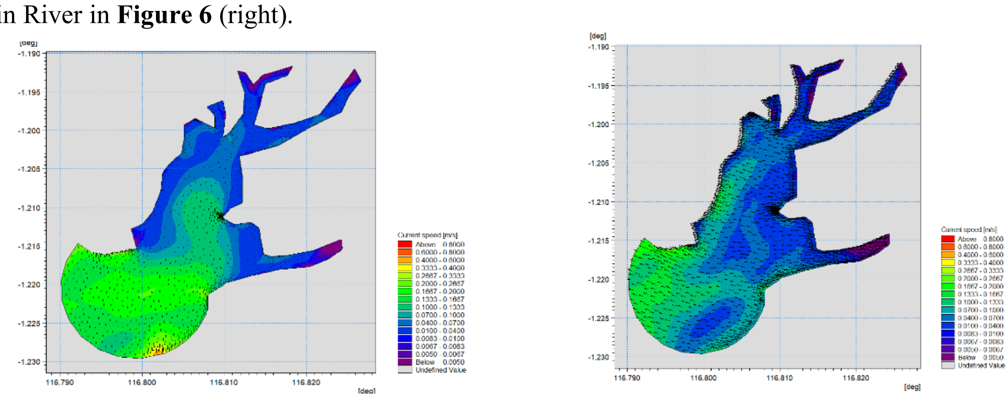

Figure 6. Modeled tidal current vectors during ebb (left) and flood (right) conditions.

Table 7. Comparison of measured and modeled current speeds at selected locations.

Current Model (m/s)	Current Survey (m/s)	Current Direction	Current Model (m/s)	Current Model (m/s)	Current Direction	Current Model (m/s)	Current Survey (m/s)	Current Direction
	0,2	BL 329		0,21	T 108		0,2	TG 137
0,12	0,1	U 355	0,23	0,21	TL 55	0,13	0,1	BL 328
	0,2	T 71		0,21	T 108		0,2	TL 60
	0,2	B 269		0,1	TL 25		0,1	B 253
0,13	0,2	BD 237	0,13	0,1	BL 326	0,1	0,1	TG 128
	0,1	T 103		0,1	U 357		0,1	S 167
	0,1	TG 12		0,2	T 92		0,2	TG 137
0,1	0,1	BL 297	0,23	0,2	TL 28	0,13	0,1	BL 328
	0,1	TL 40		0,1	U 8		0,2	TL 60
	0,1	B 269		0,1	BD 236		0,1	BD 236
0,12	0,1	BD 237	0,1	0,1	U 357	0,1	0,1	B 249
	0,1	TL 59		0,1	BL 337		0,1	BD 229
	0,1	BD 222		0,13	BL 30		0,3	BD 205
0,16	0	TL 46	0,2	0,2	T 78	0,21	0,3	BD 237
	0,2	U 355		0,2	B 262		0,3	T 87
	0	BD 241		0,1	T 76		0,3	TG 143
0,2	0,2	BP 233	0,1	0,1	B 250	0,11	0,1	T 83
	0,1	BD 205		0,1	T 102		0	BD 229
	0	BL 315		0,3	T 92		0,1	S 200
0,13	0	TL 29	0,24	0,2	T 95	0,1	0,1	T 16
	0,1	S 158		0,3	BL 239		0,1	T 88
	0,2	U 12		0,1	T 90		0,1	TL 31
0,11	0,1	T 69	0,14	0,1	U 364	0,05	0	TG 144
	0,1	BL 336		0,1	TL 24		0,05	T 73
	0,13	TL 40		0,2	BL 329			
0,15	0,1	T 88	0,3	0,2	BL 309			
	0,1	T 91		0,15	T 72			
	0,1	T 111		0,1	B 253			
0,14	0,1	U 345	0,1	0,1	TG 128			
	0,1	T 46		0,1	S 167			

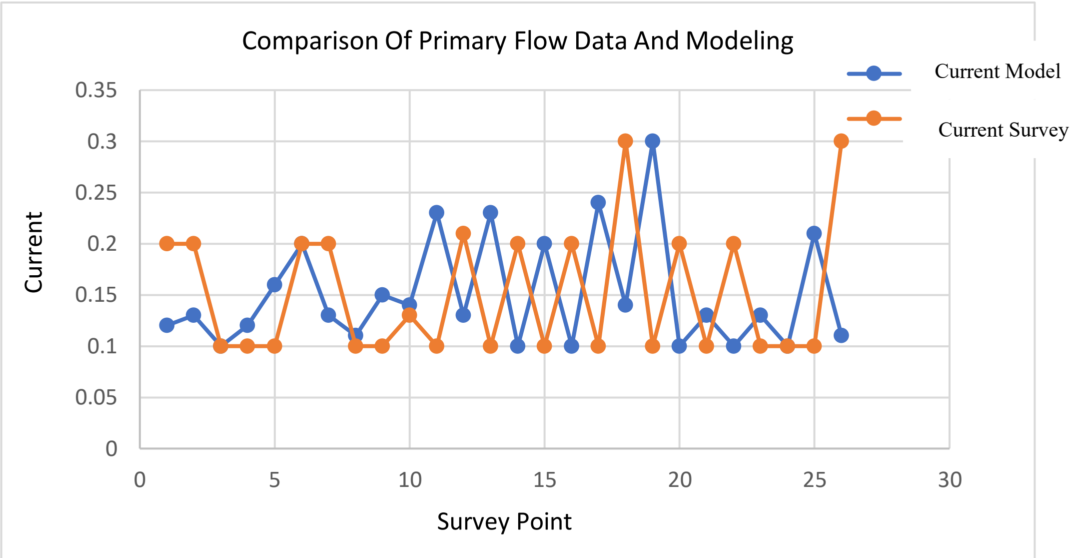

Figure 7. Comparison Of Primary Flow Data And Modeling

CONCLUSION

Current pattern modeling was performed using MIKE 21 Hydrodynamic software. Modeling was performed over a 15-day period from June 1, 2023, at 00:00 to June 15, 2023, at 00:00, with an interval of 3600 seconds per timestep. Based on the modeling, it is known that the current pattern during the high tide period has a higher speed than the current conditions during the low tide period. The tidal current can reach a speed of 0.3 m/s - 0.4 m/s, while during the low tide period, the current only ranges from 0.1 m/s - 0.2 m/s. The current direction during high tide is towards the Wain River, while during low tide it is towards Balikpapan Bay. The water depth around the Wain River is 1 m - 5 m. The tidal pattern of the Wain River is a mixed double diurnal pattern.

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