The hydrodynamics condition of water operating area for flight test site selection of N219 Amphibious aircraft

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Abstract. This research aims to assess the hydrodynamics condition of the water area for site selection of that purpose. The bathymetry data of Karimunjawa Island were obtained from the 1986 Pushidrosal bathymetric map. Furthermore, wind direction, wind speed, wave height and direction, and tidal data around the waters of Karimunjawa Island were input in hydrodynamic and spectral modelling using MIKE 21 HD-SW. West monsoon and east monsoon were applied in this model. The validation result between hydrodynamic modelling and Tidal Model Driver (TMD) data is 98.89%. The surface elevation around the domain has a range of 0.072 - 0.5 m. The average water depth at the seaplane dock plan is about 2.5 m from MSL. The hydrodynamic modelling results show that the surface elevation value at the seaplane dock plan location shows that the sea level is between -0.467 to 0.473 m (in both west and east season). The current velocity at the planned seaplane dock site in both the west and east monsoons is relatively slow (<0.185 m/s). The dominant wave direction is southeastward in the east and west monsoons. The dominant Hs is about 0.23 – 0.6 m in both seasons. At the planned water operating area, the average of Hs is 0.23 m - 0.36 m. Generally, this location fulfills the criteria of site selection for the flight test location of N219A.

Keywords: hydrodynamic, spectral wave, seaplane dock, N219 amphibious

1. Introduction
Indonesia's geographic condition, an archipelago stretching 81,000 km long, demands the construction of fast transportation modes that can effectively connect small islands. One of the ideas for such transportation was the development of an amphibious aircraft. The Amphibious Aircraft Development Plan (N219) is in line with the 2020-2024 National Medium Term Development Plan [1] and the 2015-2035 National Industrial Development Master Plan [2]. In 2023/2024, Indonesia will target to be able to produce amphibious aircraft. The N219 Amphibious Aircraft is a development of the N219 aircraft designed as a multi-functional amphibious aircraft that can be used as a passenger and cargo aircraft, for military purposes, even as a disaster relief aircraft. Several types of flights can be carried out by amphibious aircraft, namely 1. sightseeing, provided onboard tours, 2. Aller-retours, single flights, and 3. flights with sights and stops [3]. Amphibious aircraft are very useful to connect isolated areas in Indonesia. In amphibious aircraft, calculations are needed to know the conditions and factors that affect the aircraft's configuration. These factors include the mass of the aircraft, procedures, and pressure.
altitudes by the aircraft's altitude. Weather and environmental factors also affect the inspection of the aircraft, namely ambient temperature, wind, runway slope, actual position from the start of take-off, and runway surface conditions [4].

It needs a seaplane base or water aerodrome for supporting the operational facilities of amphibious aircraft. A seaplane base is one of the transportation facilities solutions for archipelagic countries [5]. These facilities consist of offshore and shoreline facilities. The estimated factors for the operating water area and shoreline facility are the water current strength, water depth, and wave action [6]. Therefore, it requires hydrodynamic modelling and waves modelling as structural design considerations. As an initial stage of hydro-oceanographic studies for planning and design, determining hydrodynamic and wave conditions in the seaplane base site needed computational studies and modelling.

A seaplane dock, a simple part of a seaplane base, is an important part of amphibious aircraft development, especially during the flight test phase. The N219A will conduct a flight test on landing and take-off in the water area in this facility. Therefore, we conducted the study on the criteria and alternative locations for constructing the N219 Amphibious aircraft seaplane dock. It needs specific conditions in the wave, current, bathymetry, and wind condition for their operational safety.

One of the potential alternative areas for seaplane dock is Karimunjawa island (see Figure 1). The location is in the northern waters of Java Island with coordinates -5.84°S and 110.46°E and a total area of 111.625 ha. The Karimunjawa islands have 5 inhabited islands, namely Karimunjawa, Kemujan, Parang, Nyamuk and Genting islands [7]. Research [8] has investigated the potential of current velocity on Karimunjawa Island as a power source with the highest current velocity of 1.1 m/s.

Based on research [9], it was found that the maximum wave height and period around Karimunjawa Island were 0.38 m and 2.9 seconds. In contrast, the significant wave height and period were 0.231 m and 1.578 seconds. The wave modelling was carried out using the SMS 10.00 software, the CMS-Wave module. Spectral wave (SW) modelling has been modeled by [10] using wind data from ogimet, as well as field wave height and period data based on the SonTek Argonaut-XR ADCP tool on 22 – 27 May 2016. Research [12] has conducted a flow velocity analysis in graphs based on ADCP recorded data. Sediment transport modelling has also been carried out by [13]. Previously, hydrodynamic modelling with MIKE 21 flow model was based on ADCP field data during the west and east monsoons.

Hence, this study and modelling were carried out based on existing secondary data. These secondary data were obtained and generated from competent institutions and valid models. This hydrodynamic modelling aims to obtain the current and wave condition around Karimunjawa Islands. For seaplane base design purposes, wave modelling was done using the MIKE 21-SW software to determine the
conditions representing extreme wave heights at the 50-year return period in the Karimunjawa Islands. The results of this modelling can be used as one of the considerations to determine whether Karimunjawa Island is suitable for the seaplane dock.

2. Materials and Method
This research and modelling were carried out using a numerical computational facility at the Laboratory for Harbor Infrastructure and Coastal Dynamics Technology (BTIPDP), BPPT. The simulations used the HD-SW modelling with MIKE 21 HD SW software [14]. The flexible mesh is applied in the modelling, in which 1920 meshes are generated within a domain area of 25.97 x 25.7 km.

Tidal data obtained from the Tide Model Driver (TMD) at an interval of 1 hour are applied at each domain boundary of the HD-SW model [15]. The speed and direction of the wind, significant wave period and height, and wave direction data could be downloaded in ECMWF (European Center for Medium-Range Weather Forecast) for 11 years (2009-2020) with a time interval of 3 hours and a resolution of 0.5°x0.5° [16] and bathymetry data obtained from Indonesian Navy Hydrographic and Oceanographic Center (Pushidrosal) [17], The General Bathymetric Chart of the Oceans (GEBCO) [18] and BatNas [19] (Figure 2).

During the west monsoon, the HD-SW modelling was carried out for a modelling period of 5 December 2019 to 5 March 2020. In contrast, in the east monsoon, it was done from 1 June 2020 to 1 September 2020. Furthermore, a whole year modelling of HD-SW was also carried out to determine the occurrence or frequency of waves more than 0.3 m high. The results of HD-SW modelling provide variations of current and wave conditions during a certain period (west & east monsoon).

The representative wave height and period are represented in the following equations [20]:

\[ H_{rep} = \sqrt{\frac{\sum_{i=1}^{N} H_i^2 T_i}{\sum_{i=1}^{N} T_i}} \]  
\[ T_{rep} = \frac{\sum_{i=1}^{N} T_i}{N} \]

Note:
N = Number of significant wave height (Hs) and period data
H = The value of Hs (m)
T = Significant wave period (second)

The results of hydrodynamic modeling will be validated against tidal data from Tidal Model Driver (TMD) using the normalization root mean squared (NRMSD) formula, as follows:

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Figure 2. Bathymetry map around the planned location on Karimunjawa Island
\[ RMSD = \sqrt{\frac{\sum_{t=1}^{T}(x_{1,t} - x_{2,t})^2}{T}} \]  
\[ NRMSD = \frac{RMSD}{y_{max} - y_{min}} \]  

3. Results and Discussion

3.1 Tidal Analysis

Based on the interpolation of data obtained from Pushidros, BatNas, and GEBCO, a bathymetric map of Karimunjawa Island and its surroundings is obtained in Figure 2. The depth of the waters around Karimunjawa Island is about -2 to -20 m. The seaplane dock site in Karimunjawa is located around the waters to the east of Dewandaru Airport at Karimunjawa (coordinate 5°48′6.08″ S; 110°29′18.90″ T).

Harmonic analysis of the recorded data is carried out to obtain important water level elevation values using tidal data from TMD and the formulation from [21] calculated it:

| Table 1. Tidal constituents in Karimunjawa |
|-------------------------------------------|
| Constituent | Amplitude (m) | Phase Angle (°) |
| M2          | 0.0309        | 45.7            |
| S2          | 0.0821        | 259.4           |
| K1          | 0.2631        | 240.03          |
| O1          | 0.0851        | 144.24          |
| N2          | 0.014         | 354.53          |
| P1          | 0.0757        | 244.64          |
| K2          | 0.0088        | 327.31          |
| Q1          | 0.009         | 73.57           |

Based on the tidal analysis calculations, the maximum tidal range is 1.158 m. The Formzahl Number (F) is 3.081, according to Table 1. Furthermore, the tidal type in the Karimunjawa Islands is a single daily type (diurnal tide), i.e., one high tide and one low tide in a day. Harmonic analysis calculations using tidal constants in coordinate -5.788°S and 110.497°E are shown in Table 2.

| Table 2. The result of harmonic analysis in Karimunjawa island. |
|---------------------------------------------------------------|
| Harmonic analysis calculations                               |
| The highest astronomical of tidal (HAT)                      | 0.569 m |
| The highest High Water Level (HHWL)                         | 0.546 m |
| The mean high water level (MHWL)                            | 0.379 m |
| The mean sea level (MSL)                                    | 0.000 m |
| The mean low water level (MLWL)                             | -0.379 m|
| The chart datum level (CDL)                                 | -0.461 m|
| The lowest low water level (LLWL)                           | -0.546 m|
| The lowest astronomical of tidal data (LAT)                  | -0.569 m|

3.2 Secondary Data Analysis

Based on the wind and wave data processing results for 2009-2020 around Karimunjawa island, it is known that the pattern of wind and wave directions in each season tends to be the same. Based on the
data for 2009-2020, shown in Figure 3, it can be seen that the wind direction is dominated by the east (32.7%) and the west (24.8%), with the dominant speed between 5.7 - 8.8 m/s (40.8%). At the west monsoon, the wind direction is dominated from the west (65%), while the dominant wind speed is 40% in the speed range of 5.7 to 8.8 m/s. Meanwhile, at the east monsoon, the wind direction is dominated from the east (60%) while the dominant wind speed is (64%) ranging from 5.7 - 8.8 m/s.

The highest average wind speed occurs at the west monsoon, with a value of 5.19 m/s. In contrast, the highest wave height and period occur in the east monsoon with the value of 0.581 m and 4.563 seconds.

**Figure 3.** Conditions of wind speed and wave height around the planned location of the Karimunjawa Island seaplane dock in each season based on data from 2009 – 2020.
3.3 Hydrodynamic and Spectral wave Modelling Analysis

Figure 4 shows that the current velocity at the seaplane dock location in the west and east seasons is relatively slow (<0.185 m/s). The south-easterly current is dominant in the west monsoon, while in the east monsoon, it is to the northwest (Figures 5 and 6). It can also be seen in the stick-plot of the current direction during January and July (Figures 7 and 8). The current direction at this location is generally back and forth following the tides, namely northwest-southeast. However, there is a dominant direction in the west and east monsoons. Based on Figure 4, it can be seen that the current velocity conditions during the west monsoon are higher than in the east monsoon. During the west season, the current velocity ranges from 0 to 0.15 m/s around the planned location. During the east season, the current velocity range around the design location has a value of < 0.08 m/s. Validation is carried out to measure the level of confidence in the modeling results. Using NRMSD calculation with formulas 3 and 4, the validation value between the modeling results and tidal data from TMD is more than 98.89%.

![Figure 4](image1)

**Figure 4.** Current velocity conditions around Karimunjawa Island during the west season (left) and east season (right) when conditions are approaching high tide.

![Figure 5](image2)

**Figure 5.** The current rose diagram at seaplane dock location plan in the west season

![Figure 6](image3)

**Figure 6.** The current rose diagram at seaplane dock location plan in the east season

Based on the extraction of surface elevation at the planned location of the seaplane dock from the hydrodynamic modelling results, the maximum sea level is 0.466 m (in the wet season) and 0.472 m (in the east season). Based on applicable regulations, seaside amphibious aircraft handling facilities require a surface elevation variation of up to 1.8 inches or equivalent to 0.457 m. The facilities that can help are floating structures and coastal buildings with moderate slopes. Meanwhile, if the change in surface elevation reaches more than 1.8 m, special accommodation is needed for seaplanes [6].
In general, the current conditions in Karimunjawa waters meet the requirements for seaplane docks since their velocity is usually less than 0.5 m/s. According to [22] Director General of Civil Aviation Regulation No. SKEP/27/VIII/2010 concerning Manual of Standard CASR Part 139 Vol III Seaplane Waterbase, the current speed must not exceed 5.5 km/h (1.53 m/s). Based on [6], the recommended current speed for amphibious aircraft landing and taking off is less than 3 knots or equivalent to 1.54 m/s. In addition, if the current speed exceeds the recommended one, it can cause some obstacles in the handling of amphibious aircraft, for example, during taxiing mode and shore operations.

Numerical wave modelling has been reviewed by [23], and it depends on the various characteristics of the ocean as input. So that numerical modelling can be developed accurately. The main input of wave modelling is wind fields. MIKE 21 SW is a third-generation wave model, and it has a specialty for the
coastal region. An accurate result in coastal or shallow water areas needs a fine mesh on bathymetry input [23].

Figures 9 and 10 show the condition of wave height around the planned location during the west and east monsoons. In addition, the direction of the wave at seaplane dock location plan is shown in Figures 11 and 12. Based on the extraction results at the planned location of the seaplane dock, it can be seen that, in general, the wave distribution pattern and wave height in both seasons are similar. In the west monsoon, the significance of wave height (Hs) dominantly is less than 0.3 m and has a maximum value of 0.9 m with an average of 0.23 m. In the east monsoon, the dominant value of Hs in Karimunjawa island is 0.3 to 0.6 m and a maximum value of 0.95 m with an average wave height of 0.36 m at the point of the seaplane dock construction plan. Wave height conditions at calm waters are around 0.0762 to 0.1524 m. At the same time, the recommended wave height for amphibious aircraft with an average weight of fewer than 3000 pounds is 0.381 to 0.45 m. Meanwhile, larger amphibious aircraft, which is around 3000 to 5000 pounds, can be operated safely by the recommended maximum wave height of 2 feet or 0.6 m [6].

The water depth at the planned seaplane dock construction is less than 0.5 m from MSL based on bathymetry data. According to [22] and [24], the measured water depth at low water levels in the water runway should not be less than 1.8 m (6 ft.). So, it must be dredged.

![Figure 11. Diagram of the wave rose at seaplane dock location plan in the west season](image1)

![Figure 12. The wave rose diagram at seaplane dock location plan in the east monsoon](image2)

**Table 3. Results of representative wave modelling in Karimunjawa during the west and east season**

|                  | West Season | East Season |
|------------------|-------------|-------------|
| significant wave | 0.113       | 0.575       |
| height (m)       | 1.450       | 3.867       |
| wave period (s)  |             |             |
|                  |             |             |

Representative wave modelling is carried out using the input from calculating representative wave height for 11 years (2009-2020). Figure 13 shows representative wave conditions during the west and east monsoons in Karimunjawa Island. The values of significant wave height and wave period during the west and east monsoons on Karimunjawa Island are shown in Table 3.

To design coastal infrastructures and climatic conditions of wind and waves, it is also necessary to calculate the wave height and wave period for certain return periods. In this study, the return period of height and wave period calculation is carried out for a return period of 1 – 100 years. Based on calculations using the Gumbel distribution method (Fisher-Tippett Type I), the wave height and period for a return period of 1 – 100 years are shown in Table 4. The purpose of Gumbel distribution is to
provide a high degree of suitability for time series extreme conditions, such as extreme wave height [25].

The research of [26] explained the wind wave modeling in the Natuna Sea that the analysis of extreme values with the Gumbel distribution was carried out to calculate the return period with a longer time than the existing data. Another research also carried out an extreme value analysis with the GEV (Generalized Extreme Value) distribution to obtain the extreme value of the residual water level at the west of the Java Sea for 100 years [27].

| Year(s) | Hr (m) | Tr (s) |
|---------|--------|--------|
| 1       | 2.60   | 8.52   |
| 5       | 3.03   | 9.40   |
| 10      | 3.21   | 9.78   |
| 25      | 3.46   | 10.28  |
| 50      | 3.64   | 10.65  |
| 100     | 3.82   | 11.03  |

**Table 4. Return period of wave height and wave period in Karimunjawa**

[Figure 13. The wave height modelling is based on representative waves in 2009 – 2020 in the west season (left) and east season (right).]

[Figure 14. Wave height modelling based on representative wave calculations for the 50-year return period with the westerly.]
The modelling of representative waves at the 50-year return period is carried out using the wave height of the 50-year return period as input (Figure 14). Based on the input wave height, the SW modelling is carried out with an angle of incidence of 90°. Within the seaplane operational planned area, the 50-year return period wave height was 1.4 m.

4. Conclusion
The tidal type in the Karimunjawa Islands is a single daily type (diurnal tide); there is one high tide and one low tide in one day. The wind direction is dominated by the east (32.7%) and the west (24.8%), with the dominant speed between 5.7 - 8.8 m/s (40.8%). The results of the HD-SW model using MIKE21 were validated against TMD tides, with an agreement of 98.89%. Karimunjawa Island meets the requirements for the seaplane dock site. However, the water depth at the planned development location is still very shallow, and dredging is necessary to meet the minimum depth of 1.8 m. About 58% of the waves at the planned seaplane dock location have a significant wave height of less than 0.3 m. Based on current conditions, the proposed location in Karimunjawa Island is suitable to be developed as a seaplane dock because it is much smaller than the maximum value of 5.5 km/hour or 1.53 m/s. In the operational planned area, the 50-year return period wave height is 1.4 m.

Author Contributions
In this study, all authors are the main contributors. HK, MW preprocessing data, setup and modelling, analysis of modelling results. WH and KS make scenarios and analysis of modelling results. All authors reviewed this manuscript.

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