**Faculty of Engineering**

# Two-dimensional Hydrodynamic Modelling of Tides at Triso Island, Burung Island and Nearby River Mouths using Delft3D

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# Two-dimensional Hydrodynamic Modelling of Tides at Triso Island, Burung Island and Nearby River Mouths using Delft3D

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## DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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# ABSTRACT

National efforts to reduce energy dependency on fossil fuels have prompted the examination of macrotidal nearshore sites around the Malaysian coastline for potential tidal stream resource development. A number of prospective tidal energy sites in the Sarawak state of Malaysia have been identified, but the local hydrodynamics of these sites are often poorly understood. Tidal energy developers rely on detailed characterization of tidal energy sites prior to turbine installation and field trials. Although first-order appraisals may make macrotidal tidal straits appear attractive for development, detailed, site-specific hydrodynamic and bathymetric models are important for determining site suitability for tidal stream turbine (TST) installation. Therefore, in this research study, a site-specific regional hydrodynamic model was set up for a previously known macrotidal site of Triso Island in Sarawak, to understand the tidal characteristics and to determine the areas of higher tidal stream energy density. Sensitivity analysis has been carried out to get the most suitable values for the model parameters, including time step, Manning's coefficient, Horizontal Eddy Viscosity (HEV), and grid resolution. The suitable values of these parameters were chosen based on criteria of RMSE value of 20 cm for water level. The model has been validated against water level by comparing it with TPXO output data. It was observed that changes on horizontal eddy viscosity and time step do not have any effect on the model performance, while the best value of the Manning's coefficient to compute bottom roughness was observed to be 0.025 $s/m^{1/3}$. Two sites near Triso Island and Burung Island are identified to be best for tidal energy harnessing among all, the maximum energy density at Triso Island and Burung Island was noted to be 0.4 kW/$m^2$ and 0.6 kW/$m^2$, respectively.

**Keywords:** Tidal energy, hydrodynamic modelling, Delft3D modelling, Renewable Energy Sarawak

***Pemodelan Hidrodinamik Dua Dimensi Pasang Surut di Pulau Triso, Pulau Burung dan Mulut Sungai Berdekatan Menggunakan Delft3D***

## *ABSTRAK*

*Dalam usaha negara untuk mengurangkan kebergantungan tenaga bahan api fosil telah merintis kajian makrotidal pantai di sekitar pantai Malaysia untuk potensi pembangunan sumber aliran pasang surut. Beberapa tapak tenaga pasang surut berpotensi di negeri Sarawak, Malaysia telah dikenal pasti, namun hidrodinamik tempatan tapak ini belum dikaji. Pemaju tenaga pasang surut bergantung pada pencirian terperinci tapak tenaga pasang surut sebelum pemasangan turbin dan ujian lapangan. Walaupun penilaian peringkat pertama boleh menjadikan selat pasang surut makrotidal agak menarik untuk pembangunan, model hidrodinamik dan batimetri khusus tapak yang khusus adalah penting untuk menentukan kesesuaian tapak untuk pemasangan turbin aliran pasang surut (TPS). Oleh itu, dalam kajian penyelidikan ini, model hidrodinamik khusus tapak disediakan untuk tapak makrotidal pulau Triso di Sarawak yang diketahui sebelum ini, untuk memahami ciri pasang surut serta untuk menentukan kawasan yang mempunyai ketumpatan tenaga aliran pasang surut yang lebih tinggi. Analisis sensitiviti telah dijalankan untuk parameter model untuk mendapatkan nilai optimum model, dan model telah disahkan terhadap paras air dengan membandingkannya dengan data keluaran TPXO. Telah diketahui bahawa perubahan kelikatan pusar mendatar dan langkah masa tidak mempunyai apa-apa kesan ke atas prestasi model, manakala nilai terbaik pekali kendalian untuk mengira kekasaran bawah diperhatikan ialah 0.025* $s/m^{1/3}$*. Dua tapak berhampiran pulau Triso dan pulau Burung dikenal pasti yang terbaik untuk memanfaatkan tenaga pasang surut, ketumpatan tenaga maksimum di pulau Triso dan pulau Burung dicatatkan ialah 0.4* $kW/m^2$ *dan 0.6* $kW/m^2$.

***Kata kunci:*** *Tenaga pasang surut, pemodelan hidrodinamik, pemodelan Delft3D, Tenaga Boleh Diperbaharui Sarawak*

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADCP | Acoustic Doppler Current Profiler |
| ADI | Alternating Direction Implicit |
| AOI | Area of Interest |
| APD | Average Power Density |
| AR | Aspect Ratio |
| CD | Chart Datum |
| CMEMS | Copernicus Marine Environment Monitoring Service |
| CRES | Combined Renewable Energy Resources |
| GEBCO | General Bathymetric Chart of Oceans |
| HEV | Horizontal Eddy Viscosity |
| MCE | Multi Criteria Evaluation |
| OTEC | Ocean Thermal Energy Conversion |
| OTIS | Oregon State University Tidal Inversion Software |
| RMSE | Root Mean Square Error |
| SMD | Sarawak Marine Department |
| SSI | Site Suitability Index |
| TEC | Tidal Energy Conversion |
| TMD | Tide Model Driver |
| TPXO | Oregon State University TOPEX/Poseidon Global Inverse Solution tidal model |
| TST | Tidal Stream Turbine |
| UK | United Kingdom |

# CHAPTER 1

# INTRODUCTION

## 1.1 Study Background

Coastal areas of the sea are considered as vigorous vicinities as they create a boundary between ocean and land, where intensive exchange processes occur quite frequently. Coastal areas of the sea are also important zones for economic development, by providing an opportunity in terms of fishing, transportation, and energy generation. Observing the hydrodynamics and circulation patterns of the tides at coastal zones need rigorous data collection strategies, that need a lot of time, effort, and significant expenses. However, the numerical models are an attractive option to understand the hydrodynamics and circulation patterns of tides, close to coastal zones. In view of the economic significance of these zones, several numerical models are developed to simulate the sea and land interaction process such as tidal flow, wind current, sediment transport, wave interaction, salinity, temperature distribution, et cetera (etc) (Chen *et al*., 2013; Guillou *et al*., 2020; Hagerman *et al*., 2006). As most of the coastal zones have shallow water, therefore developing a 2-dimensional (2D) model is considered valid to understand the tidal patterns, by averaging the depth of shallow water (Alhunaiti *et al*., 2021).

The depth-averaged models help understand the local hydrodynamics of macrotidal sites. The understanding of the spatial and temporal changes in the flow field at a tidal site is the initial step to making a macrotidal site an energy generation spot. The initial stage of tidal energy development is the site screening, for which hydrodynamic modelling plays an important role in the inclusion and exclusion of potential areas for tidal energy harnessing within the macrotidal site. After the initial stage, high-resolution hydrodynamic modelling needs to be done to characterize the site for energy extraction based on energy density, distribution of the mean, and peak tidal current speed, and the water depth. Thanks to the research community around the globe for their interests in tidal energy exploration, as a result of which, several numerical, hydrodynamic models, packages, and open source software have been available (Carballo *et al*., 2009; Chen *et al*., 2013; Cossu *et al*., 2021; Deltares, 2021; Guillou *et al*., 2020; Hagerman *et al*., 2006). Utilizing these packages, especially the open-source packages, make it easy for the young scientists, engineers, and industrial community in the tidal energy exploration field to characterize an unexplored tidal energy site and to optimize site selection and turbine form design. One example of such packages is the Delft3D open-source package developed by the Deltares (2021) to solve the shallow water equations and understand coastal hydrodynamics (Deltares, 2021). Delft3D is a hydrodynamic and transport simulation package that can be modelled as 3-dimensional (3D) or 2D, during simulation, the software package computes the non-steady flow resulting from metrological and tidal forces. The Delft3D open source package has a history of successful simulation application of water flow in sea, ocean, coastal, and estuarine sites. Therefore in this study, we utilized the numerical application of Delft3D to simulate the tidal flow at Triso Island, Sarawak Malaysia.

### 1.2 Problem Statement

Tidal energy development in Malaysia is still in infancy stage. Malaysia’s large coastline has potential sites for tidal energy harnessing. However, extensive studies are still required to make them feasible for power generation and to justify these sites for onsite testing of tidal current turbines for power generation. In recent years, some researchers have already taken their part to explore the tidal stream energy generation sites in Malaysia (Goh *et al*., 2020; Lim & Koh, 2010; Sakmani *et al*., 2013). The majority of tidal stream energy sites assessments are focused on the Strait of Malacca. The major tidal energy sites available in the Strait of Malacca have gone through the initial feasibility assessment, and are justified for the onsite testing of tidal current turbines. The assessment was done by developing high-resolution 2D and 3D hydrodynamic models. These hydrodynamic models enable researchers and policymakers to make sure that the estimated tidal energy density was not overestimated. Furthermore, the accuracy of the assessment was justified by assuming the porous plate in the hydrodynamic model to be a tidal current turbine. This way, the effect of installing the turbines at different locations and the optimized sizing and configuration of the turbine array were analyzed. However, these studies are focused on the Strait of Malacca only and not much attention has been given to the other sites in Malaysia. There are several potential locations across the Malaysian coastal zones that can be utilized for tidal stream power generation. These untapped locations include the coastal zone near the Langkawi Island in Malacca strait, Seri Buat Islands on the East coastline of peninsular Malaysia, the West coastal zone of Sarawak State, and a lot of sites in Sabah State (Goh *et al*., 2020; Lim & Koh, 2010; Sakmani *et al*., 2013). Another study by Rigit *et al*. (2013) also suggests several locations in Sarawak, see Figure 1.1 (Rigit *et al*., 2013). The tidal sites suggested by Rigit *et al*. (2013) have higher tidal current speeds when compared to sites in the straits of Malacca (Sakmani *et al*., 2013). The mapping of the potential sites in Sarawak was done by Rigit *et al*. (2013) based on the statistical analysis of the tidal stream speed data available in Sarawak Tidal Stream Tables (Rigit *et al*., 2013). A total of 6 sites in Sarawak were analyzed from the Sarawak Tidal Stream Tables, as shown in Figure 1.1. These include Kuala Igan, Bintulu, Off Tanjung Sirik, Off Kuala Paloh, Off Kuala Rajang, and Off Tunjung Po locations.


**Figure 1.1:** Potential tidal stream energy sites in Sarawak (Rigit *et al*., 2013)

Among these sites, Kuala Igan has the highest tidal stream speed, as well as meets the depth requirements of 15 m for installing tidal current turbines. Furthermore, on-site measurements were recorded for the location Triso Island, and it was noted that the Triso Island has the highest tidal stream speed of 2.06 m/s, compared to any other site in Sarawak. This site was suggested for further future study, as sufficient data was not available for the resource assessment.

Furthermore, the mapping done by Rigit *et al*. (2013) is based on the statistical analysis only, which is not sufficient to characterize the tidal energy resource site (Rigit *et al*., 2013). Triso Island in Sarawak was suggested as the most attractive location for tidal stream energy harnessing, but no one has completed the further study so far. The locations were identified based on statistical analysis, but the local hydrodynamics of these locations are still not understood yet. Moreover, understanding the local hydrodynamics is the initial step in the tidal energy assessment of any site. Therefore, in this study, we set up a regional hydrodynamic model for Triso Island, by utilizing the numerical application of Delft3D. In this way, the hydrodynamical characteristics of tides at Triso Island, Sarawak, can be understood. This further helps to determine the tidal stream power density available at the proposed site and to decide the inclusion and exclusion areas for tidal energy harnessing at the Triso Island site.

### 1.3 Objectives

This study aims to understand the hydrodynamics of tides at Triso Island, Sarawak, by setting up a regional hydrodynamic model utilizing the numerical application of Delft3D. In particular, the objectives of this study are as follows:

i. To set up a regional hydrodynamic model for Triso Island, Burung Island, and nearby river mouths using numerical application of Delft3D

ii. To investigate the sensitivity of the model considering time step, grid resolution, Manning's coefficient, and Horizontal Eddy Viscosity

iii. To validate the model by comparing it with TPXO output data

iv. To determine the temporal and spatial characteristics of tides at Triso Island and Burung Island

v. To evaluate the kinetic energy density available at Triso Island and Burung Island

## 1.4 Scope

It is expected that the current study will be fundamental for further tidal stream energy development in Sarawak. The current study is a simulation study based on Delft3D software, which focuses on the tidal stream simulation at Triso Island. For this purpose, a regional hydrodynamic model called “Triso-Model” is set up to characterize the proposed site. The bathymetry data in the simulation is collected from Sarawak Nautical Charts and General Bathymetric Chart of Oceans (GEBCO). The data needed for setting up the boundary conditions in simulation is extracted from the TPXO output. The sensitivity analysis is carried out for the Triso-Model based on physical and numerical parameters such as time step, grid resolution, bed roughness coefficient, horizontal eddy viscosity, etc. The scope of the thesis also includes the spatial and temporal analysis of the tides at Triso Island. In this way, the inclusion and exclusion of the area near Triso Island for tidal stream power generation can be decided. Furthermore, the proposed site is characterized based on the spatial distribution of depth-averaged velocity, the temporal variation, the magnitude of the depth-averaged velocity, and the bathymetry. This characterization helps to suggest a suitable location for onsite testing of the tidal current turbine.

## 1.5 Thesis Structure

There are a total five of chapters in this thesis, the summary of each chapter is discussed below:

Chapter 1: Introduction

This chapter has provided a general introduction to the current study, focusing on the background of hydrodynamic modelling, the fundamental of tidal energy, and the tidal stream energy potential in Malaysia. Afterward, the problem statement, objectives, and the scope of the current study are also described in this chapter.

Chapter 2: Literature Review

This chapter has discussed the literature review related to the scope of the thesis. The fundamentals of tidal energy and the brief history of tidal energy generation are discussed in detail in this chapter. The chapter also focuses on the tidal energy assessment and the types and scales of tidal energy assessment. Finally, the literature review is presented on the hydrodynamic modelling approach for tidal stream energy assessment.

Chapter 3: Methodology

This chapter provides a detailed description of the methodology adopted to set up the hydrodynamic model for the Triso Island study area. The study on the site is presented to gain the knowledge about the study area. The process flow diagram in this chapter explains each step of data collection, data processing, and setting up the hydrodynamic model. The method of calculating tidal energy density is also explained at the end of this chapter.

Chapter 4: Results and Discussion

In this chapter, the main outcomes of the study are discussed in detail. The results on sensitivity analysis are presented and the model validation is also discussed in this chapter. The focus is given on the spatial and temporal analysis of depth averaged velocity at the study area to identify the best suitable locations for tidal stream energy generation. Finally, the energy density is calculated for the identified locations.