

# Numerical modelling of the Brunei coastal zone

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## Abstract

The Brunei coastline has been experiencing erosion for many years, ranging from small scale loss of beach to large scale cliff erosion which has been threatening coastal dwellings and infrastructure. This project was aimed at applying a range of numerical models to the coastal geomorphology, to assess the sediment budget and key mechanisms affecting sediment transport along the entire Brunei coastline and extending approximately 50km offshore. Numerical models which were applied included a 2D Lagrangian beach model and a hydrodynamic pollutant transport model coupled with a wave refraction model to assess both the nearshore surf zone transport and the offshore sediment transport regimes. The wave climate for the region is dominated by the Northeasterly Monsoonal conditions during the months of December to February. The objective of the numerical study was to determine the influence that coastal structures and offshore shoals have had on the coastline. The results from the numerical investigation indicate that significant wave focusing occurs at historical erosion regions and generates a nett westerly drift within the surf zone. Offshore of the surf zone, however, the numerical modelling indicated an easterly drift of sediment being indicative of a "Localised Sediment Cell" where the sand migrates along the coast towards the west and returns via ambient currents offshore.

*Keywords: numerical modelling, coastal erosion, surf zone, littoral transport, sediment budget.*

## 1 Introduction

Situated on the island of Borneo in the South China Sea, at approximately 140km in length, the coastline of Brunei represents a diverse multi-use coastal



zone ranging from expanses of oil and gas infrastructure on the western end, to recreational uses on the eastern shores.

At the eastern extent of the shoreline, Brunei Bay and Estuary exists. The Brunei Estuary represents a drainage basin for a large portion of Borneo. It contains expanses of intertidal mudflats and mangroves and is a source of fine grained sediment to the coastline. Brunei's main port (Muara Port) has also expanded over recent years to include a dredged shipping channel, breakwater extensions and Pelompong and Serasa Spits.

In addition to the Brunei Bay region, several smaller rivers discharge into the South China Sea (e.g. Tutong, and Sungai Belait, with Batang Baram to the west). Although the rivers do not significantly influence the shoreline stability, many of the river mouths along the coast are dynamic representing a balance between the river discharge, the littoral drift and the offshore ambient currents. Such dynamic river entrances cause problems for navigation and the long-term management of the Brunei Coastal Zone. Training walls have been constructed at most of the major rivers mouths along the Brunei coast.

On the western end of the shoreline, a long seawall exists between the Belait Estuary and the Tutong river, fig. 1. The seawall is in place to protect the surrounding oil and gas infrastructure from flooding. Additionally, extensive coastal protection works have been constructed along the coastline ranging from large scale breakwaters to a variety of headland breakwaters.

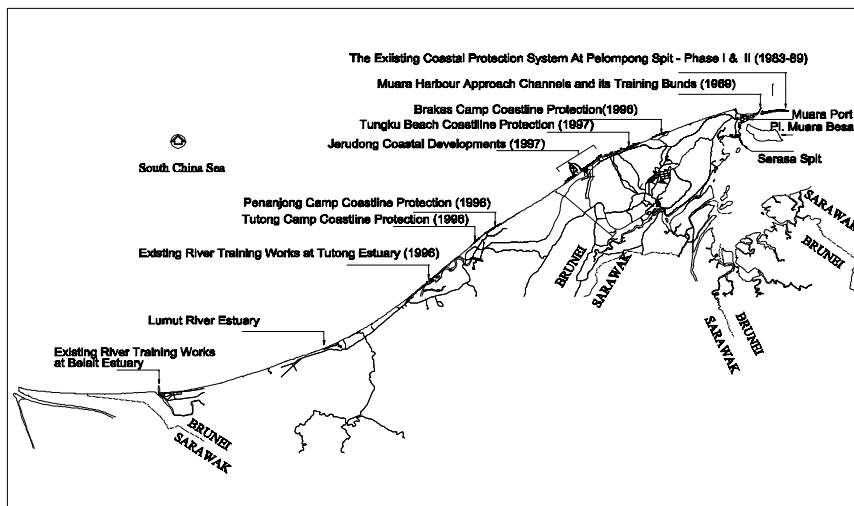


Figure 1: Coastal protection structures – Brunei Coastal Zone.

East of the Tutong river, the Brunei coastline has been experiencing erosion over many years. In some areas, the erosion has impacted on the stability of cliff faces bordering the beach, subsequently threatening local infrastructure, roads and dwellings, fig. 2. The largest section of erosion is near Penanjong Camp.

Historical evidence at this location indicated that the erosion was occurring prior to the Jerudong harbour development and that since the construction of the harbour, the rate of erosion had increased.



Figure 2: Typical cliff erosion along the Brunei coast.

The sediments along the Brunei coastline are typically fine grained with particle sizes of the order of 0.1-0.3mm with slightly coarser grained material being observed on the western extent. Generally the slopes of the beach profile are relatively flat, ranging from 1:40 to 1:50. The cliff faces and geology of the Brunei shoreline generally consist of soft cohesive material which easily erodes when subject to heavy monsoonal rainfall and higher wave activity at the base. Once the cliffs erode, the sediment from the cliffs is lost from the shoreline.

From physical evidence, the annual littoral drift is from east to west, however east of the Berakas Army Camp, the littoral drift is from west to east. The change of direction is evident from the formation of Pelompong Spit to the East prior to the construction of the Muara Port entrance channel.

Brunei is subject to two monsoonal seasons with a larger Northeasterly Monsoon during the months December to February and a smaller scale Southwesterly Monsoon during the months July to October. The Northeasterly Monsoon generally produces longer period swell conditions with wave heights of the order of 1-3m in deepwater. The waves generated during the Southwesterly Monsoon don't usually contain significant swell energy. As a

result of the asymmetric monsoonal conditions, a nett westerly littoral transport is observed.

## 2 Numerical modelling

### 2.1 Wave modelling

A key component of the sediment budget is the understanding of the offshore wave climate and its nearshore transformation. A series of nested wave models was applied to reproduce the wave climate along the Brunei coast. The first broad scale wave model applied was the 2<sup>nd</sup> generation spectral wind/wave model, WISWAVE (Resio [1], Hubertz [2]). WISWAVE is regularly applied on a global scale to reproduce the long period swell conditions, and its application to the South China Sea was necessary to reproduce the deepwater wave conditions.

For this study, two separate model nests were employed which included a 0.5x0.5 degree (~50km) model grid extending over the entire South China Sea, and a finer nest 0.1x0.1 degree (~10km) corresponding to approximately covering the Brunei continental shelf region. The extent of the WISWAVE model grids were as follows:-

“B-Grid”                    0.5°x0.5° over the South China Sea from  
10.5°S-30.5°N and 89.5°E-130.5°E,  
55.6 km spatial resolution, 1 hour time step

“C-Grid”                    0.1°x0.1° offshore Brunei from  
2.5°N-8.0°N and 111.0°E-117.0°E  
11.1km spatial resolution  
7.5 min time step

The output from the large scale WISWAVE model were calibrated against deepwater measurements obtained offshore from Brunei Shell Petroleum, with the results indicating a high correlation between the modelled data and the measured data.

Ten years of hindcast wave data were modelled to provide boundary data to the spectral wave refraction model, WBEND (Black and Rosenberg [3], Black [4]). Model WBEND is a 2-dimensional numerical wave refraction model for monochromatic waves or a wave spectrum over variable bathymetry. The model applies a fast, iterative, finite difference solution of the wave action equations to solve for wave height, wave period and breakpoint location. The WBEND wave model was applied to transform the deepwater wave climate to the surf zone, as well as providing the gridded wave climate for sediment resuspension offshore. The numerical grid resolution and extent for the WBEND model included offshore shoals which were found to significantly influence the wave climate near the shoreline.



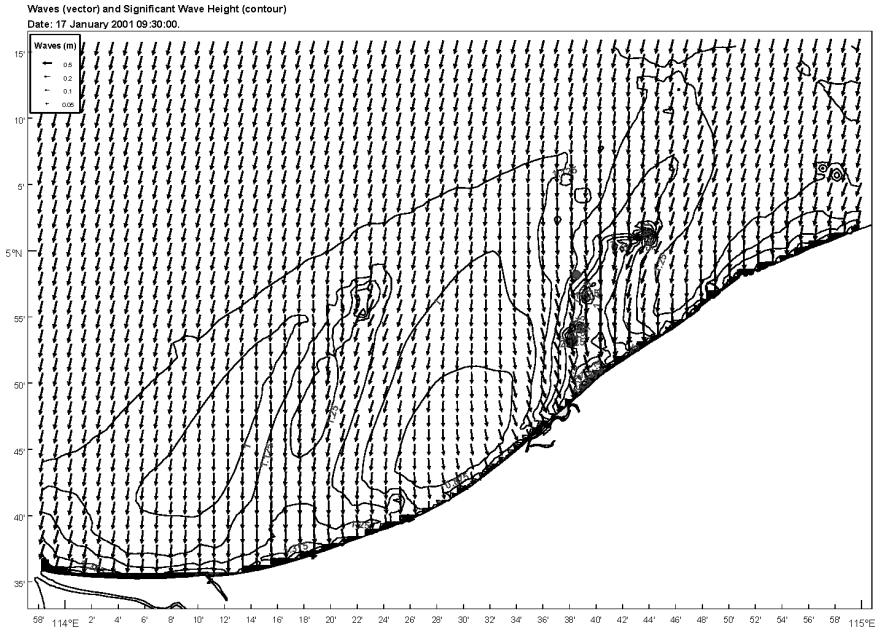


Figure 3: Typical WBEND wave refraction results showing focusing onto Penanjong region.

The results from the wave refraction modelling indicated that under typical monsoonal conditions, significant wave focusing occurs between the mouth of the Tutong River and the Jerudong marina (fig. 3). This wave focusing corresponds to the section of coastline where the major erosion has been occurring in the past. The wave focusing is primarily due to a shoal which extends approximately 50km from the coastline. Along the western end of the shoreline, the wave focusing is far less dominant being supportive of the relatively benign shoreline profile on the western shores. This result indicates that when combined with the high rainfall associated with the monsoonal conditions and the soft muddy cliff faces, the wave focusing most probably causing local erosion for many years prior to the construction of the Jerudong marina.

## 2.2 Nearshore surf zone modelling

To assess the annual littoral drift along the Brunei coastline, the model GENIUS has been applied. Model GENIUS predicts refraction, breakpoint wave conditions and longshore sediment transport on beaches. GENIUS is similar to its well-known counterpart GENESIS (Hanson and Kraus [5]) but with some extra features including frictional attenuation of wave height and a more physically-based treatment of wave transmission factors across submerged reefs. The application of the GENIUS model to the Brunei coastline required the

interpolation of a series of perpendicular transects from the coast with a grid size of 1m. The GENIUS model does not include coastal structures and was applied to determine the base littoral drift in the absence of coastal structures.

The results from the littoral drift modelling, fig. 4, were obtained from a WBEND nesting for a full year of data. The results indicate a nett westerly longshore transport with the maximum extending to approximately 200,000 m<sup>3</sup>/yr between the Tutong River and the Jerudong marina and corresponds to the point of maximum erosion along the Brunei coastline. The nett westerly transport is a result of the more severe Northeasterly monsoon conditions.

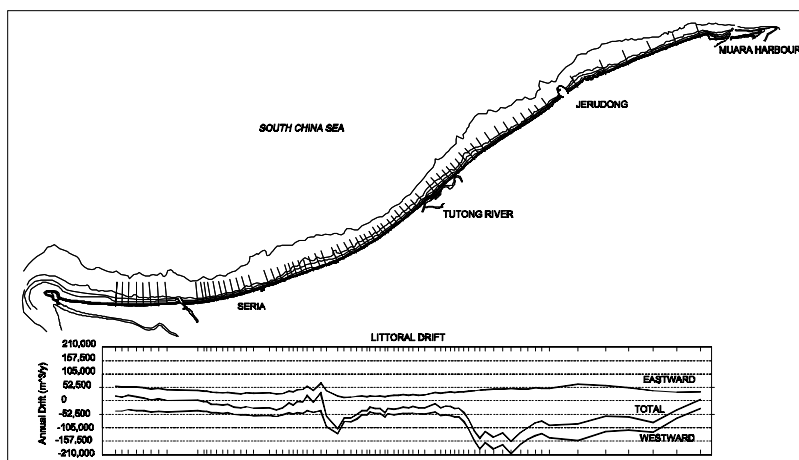


Figure 4: Annual longshore transport results.

As the GENIUS model does not include the influences of coastal structures, another more advanced model was applied to the coastline. Model 2DBEACH (Black and Rosenberg [3, 6]) is a unique beach circulation and sediment transport model that uses a mixed Lagrangian and Eulerian solution scheme to obtain highly accurate simulations over complex natural bathymetries. 2DBEACH has unprecedented capacity to predict features such as rip-currents, sand bar movement, beach transformations, storm erosion, and the build up of beaches after storms.

In 2DBEACH, the unsteady wave height transformation equations are solved using a combination of Lagrangian and Eulerian methods which eliminates numerical diffusion errors that are common to purely Eulerian solutions. The Lagrangian scheme also effectively handles the sharp discontinuity in wave heights across the breakpoint.

The results from the nearshore 2DBEACH modelling indicated that the maximum zone of sediment transport occurs offshore of the Penanjong Camp region or where the maximum extent of existing erosion is occurring at present. The results also indicated that Jerudong marina to the east prevented the

sediment supply to the western shores. This removal of sediment supply essentially removes approximately 150,000 m<sup>3</sup>/yr from the western shores which has contributed to an increased rate of erosion from near the Penanjong region.

### 2.3 Offshore hydrodynamic modelling

To determine the nett sediment transport pathways offshore from the surf zone, a series of hydrodynamic models were applied.

The hydrodynamic model used in this paper was 3DD, a coupled 3-dimensional hydrodynamic and advection/dispersion numerical model for application to vertically-stratified and homogeneous ocean, continental shelf and shallow water environments (Black [7]). The 3DD model solves for the wind and tide induced currents by solving the principle governing equations for shallow water flow. Although 3DD may be run in a fully three dimensional mode, a depth-averaged representation was used for this study.

The boundary conditions for the 3DD model simulation were derived from a broader scale finite element model (ADCIRC) which incorporated the shelf offshore of Brunei. The ADCIRC model was used to nest down tidal constituents obtained from a global tidal model to the resolution of the 3DD model boundary.

3DD is coupled to separate dispersal, sediment transport and wave refraction models. In this paper, the Lagrangian advection/dispersion model POL3DD (Black [8]) was used for the dispersal simulations. This 3-dimensional model assigns particles to represent the sediment erosion and deposition. The particles are eroded using wave information from the WBEND wave model and advected using the currents specified by 3DD. Diffusion is simulated with a Monte Carlo random walk, with separate eddy diffusivity coefficients in the longitudinal, lateral and vertical flow directions.

For each month, the measured wind data supplied by Brunei Shell were used to predict the depth-averaged tide and wind-induced circulation. Additionally, the wave refraction output from WBEND was supplied onto the same model grid as 3DD, thus providing for the wave-induced sediment resuspension offshore.

From the resulting output, estimates were produced for the sediment concentration. From the time series sediment concentration results, the data were further analysed to provide an estimate of the nett monthly sediment load and residual direction. Since for most of the time little sediment transport occurs offshore, the nett monthly load and residual direction was computed by summing the non-zero sediment transport components over each month. From each monthly result, additional summations were undertaken to determine the nett annual sediment load and principle direction of flow.

The results from the circulation modelling indicated that offshore from the surf zone, the nett sediment transport is towards the east on an annual basis. Therefore the Brunei coastline has been determined to exist within a "localised sediment cell" where there is little or no influence from sources beyond the Brunei borders, fig. 5. The easterly return transport however is smaller than the net westerly littoral transport within the surf zone. This residual offshore



sediment transport is considered to be an important mechanism for the supply of sediment to the Brunei coast in the longer term. The sediment from the rivers and estuaries consists of finer scale cohesive mud which to spreads out further across the seabed and thus not significantly influencing the stability of the shoreline.

The hydrodynamic simulations also indicated that most of the sediment transport occurs across the shoal extending out to the Champion Oil Field. This result is consistent with the wave focusing across this shoal. Typical estimates of the sediment transport correspond to approximately 30-40,000 m<sup>3</sup>/km/yr, however near Penanjong this rate is increased slightly to approximately 60,000 m<sup>3</sup>/km/year. The imbalance between the sediment moving around offshore and the potential littoral drift is believed to lead to a loss of sediment from the Brunei coastline and hence contributing to the stability of the shoreline.

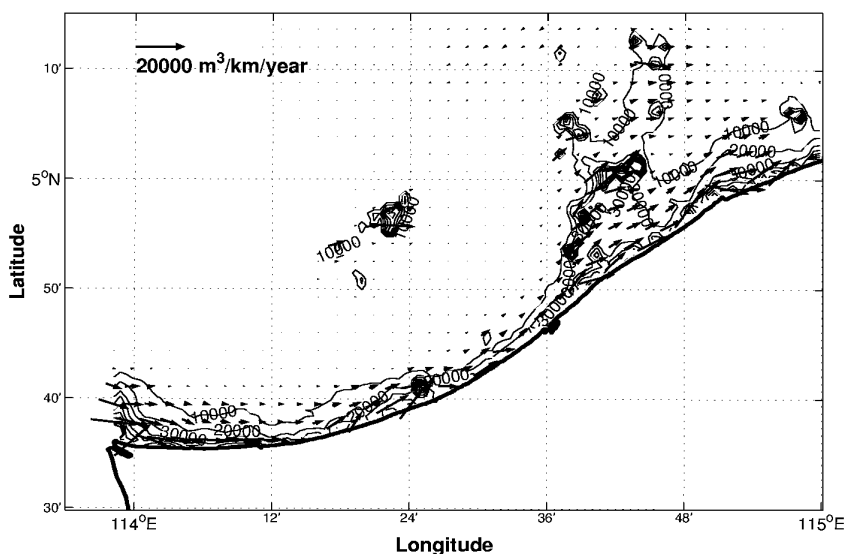


Figure 5: Nett annual offshore sediment transport (m<sup>3</sup>/km/yr).

### 3 Discussion

A series of numerical models have been applied to assess the principle mechanisms for erosion occurring along the Brunei coastline, as well as determining the sediment sources and available pathways.

The models include, a global deepwater spectral wind/wave model, a nearshore wave refraction model to transform the deepwater wave climate to the

nearshore, a beach morphology model, and hydrodynamic/pollutant transport models for the assessment of the offshore sediment pathway.

The results from the modelling indicated that in the absence of coastal structures along the Brunei coastline, the nett annual littoral drift (within the surf zone) is of the order of 150,000-200,000 m<sup>3</sup>/yr generally in a westerly direction. The westerly direction is due to the more dominant Northeasterly Monsoonal conditions which occur from December to February. This westerly transport is blocked by the construction of a large harbour in the east. However in the absence of the harbour, the general sediment trends along the section of coastline offshore of Penanjong is still significant indicating that the erosion at this section of coast was occurring prior to the construction of the harbour, and that the rate of erosion had been increased.

The results from the wave refraction modelling clearly indicated the focusing of wave energy onto the Brunei coastline as a result of offshore shoals. This wave focusing occurs for wave heights generally greater than 1.5m in deepwater. The common focusing onto key erosional sites indicates that although the wave climate does not need to be large, significant impacts on the coastline may be observed.

Offshore from the surf zone, the annual sediment direction drift is towards the east as indicated by the coupled hydrodynamic/wave/sediment transport modelling. This nett annual easterly transport indicates that the coastline of Brunei may be described as a localised sediment cell where little or no influence from external sources is possible. The imbalance between the nett easterly flow offshore and the westerly flow in the surf zone indicates that sediment is being lost from the Brunei coastline and is contributing to the erosional trends being observed.

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