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Hydrodynamic Model Calibration for Mangrove Replanting using Maximum Absolute Error and Brier Skill Score

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Abstract: Hydraulic numerical models are now widely used as a prediction tool in decision making because they are convenient and practical for projects that involved wide area, thus more cost-saving compared to physical models. Numerical modeling normally applies complicated mathematical equations, which have coefficients that are site specific. Therefore, model calibration and validation are important to facilitate accurate representation of the study area and provide high level of confidence in the model output. The Indian Ocean tsunami disaster in 2004 has increased recognition of the importance of mangroves for coastal protection; hence encouraged more replanting projects along the coast of Malaysia. Since mangrove growth is governed by many coastal processes such as tides, waves, currents, type of sediment, nutrient availability, sediment transport, erosion and deposition; careful assessment of the factors is necessary to facilitate successful replanting activities. Numerical modeling was applied for the study area at Sungai Haji Dorani, Malaysia to investigate the performance of the developed model in assessing the suitability of the study area chosen for mangrove replanting. Calibration and validation of water levels, current speed and directions at Sungai Selangor, Pintu Gedong and Sungai Haji Dorani were carried out using Maximum Absolute Error (MAE) and Brier Skill Score (BSS) for time series data. Model results show that the BSS values are between 0.73 and 0.95 for water levels and current directions while BSS for current speeds are between 0.6 and 0.84. These values indicate that the model results can be accepted since the best prediction model is when the BSS value is 1. Analysis of model results show that the average velocity over Haji Dorani coast is 0.14 m/s and peak velocities varied from 0.1 to 0.4 m/s, higher than the particle velocities for fine sand, silt and clay, which will not encourage deposition of fine sediments. Even if flocculation processes do occur, the flocculants will disintegrate when the velocity is higher and the mud will be suspended and re-suspended in the water column as the substrate is not stable enough to consolidate. If mangroves are planted in the study area, the young mangroves will be washed away by the high tidal currents since the mangrove roots are not long enough to hold on to the unstable substrate. A temporary structure would likely assist to reduce the tidal current velocities in the study area if mangrove replanting is still desirable.

Keywords Additives; Mangroves Replanting, Hydrodynamic Model, Maximum Absolute Error, Brier Skill Score

1. Introduction

Nowadays, numerical models are being used as a prediction tool to help in decision making. Some of the advantages of numerical models are that they can hind-cast physical conditions of the study area; able to predict consequences of different scenarios in much shorter time; and their cost is much cheaper compared to building physical model or implementing projects and then abandon them if they are not economically viable (Jacobsen ez a/., 2007). Numerical model also simplifies complicated mathematical and statistical equations since all required equations will be done by the computer and the desired results can be obtain in shorter time period.

To understand coastal hydrodynamics and sediment transport over large spatial areas, numerical modelling has been shown to be the best method (Toorman, 2001). Although it is not possible to reproduce all complicated processes that occur in the coastal areas, numerical models provide useful analyses interacting economic and ecological factors that are relevant for management and development of coastal areas, as they can visually display answers to socio-economic problems (Toorman, 2001).

Some hydrodynamics coefficients are varied from site to site. Therefore, there is a need for calibration and validation processes to match the model predictions and measured data on site (Sutherland er al., 2004). Evaluating performance of

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coastal numerical models is very important to establish their credibility especially in analysing lots of time series data. The normal practice is by comparing predicted results against measured data at a number of locations around the model domain, to get the best fit result (Sutherland er al., 2004). For this reason, the Maximum Absolute Error (MAE) and Brier Skill Score (BSS) had been used widely on coastal research especially on the hydrodynamic study.

The Indian Ocean tsunami disaster in 2004 had increased recognition of the importance of mangroves as the most valuable natural coastal protection. Since 2005, considerable effort had been made by the Government of Malaysia to establish mangroves in areas affected by the tsunami and damaged by rapid coastal development. As reported by most of the researchers including Massel ef al. (1999) and Teo er al. (2009), mangrove growth can be affected by numerous coastal processes such as tides, waves, currents, and the type of sediment, nutrient availability, and sediment erosion, transport and deposition. Therefore, careful assessment of the multiple factors is necessary to facilitate successful replanting.

The objective of this study is to investigate the performance of the developed numerical model by Awang (2010) in assessing the suitability of the study sites chosen for mangrove replanting projects, based on the hydrodynamic characteristics.

1.1 MATERIAL AND METHODS

The method used in the calibration of measured and model simulated data is the Maximum Absolute Error (MAE), which calculates the mean difference between the model and measured values and represents the average difference between collected field data and model simulations. Then, the quality of the modelling was judged from the calculated value of the Brier Skill Score (BSS) (Sutherland ef a/., 2004) where BSS will compare the accuracy measure of a prediction to the accuracy of a baseline prediction and used to decide whether the model is improving or deteriorating (Reeve, 2008). The equation for calculating the MAE and BSS is as follows:-

$$MAE = \langle |Y - X| \rangle$$

Where X = a set of N observed values; and
Y = a set of N predicted values of scalars (wave height or water level) or vectors (currents).

$$\langle |X| \rangle = \frac{1}{N} \sum_{n=1}^{N} |X_n|$$

$$\langle |Y| \rangle = \frac{1}{N} \sum_{n=1}^{N} |Y_n|$$

And

$$BSS = 1 - \frac{\langle (Y - X)^2 \rangle}{\langle (B - X)^2 \rangle}$$

Where
<Y> = the mean of observations;
<X> = the mean of the modelled predictions;
$\langle |Y - X|^2 \rangle$ = Mean Std. Error (MSE)
$\langle |B - X|^2 \rangle$ = Mean Change from a baseline prediction (MSC); and
B = the baseline prediction (Sutherland *et al.*, 2004):

In most morphodynamic and climatic models, the baseline prediction is assumed to be no change (Sutherland *et. al.*, 2004) and the tide is assumed to follow the Gaussian distribution (Reeves, 2008). Therefore, the BSS equation is simplified to become:

$$BSS = 1 - [(Y-X)^2 / X^2]$$

Note: BSS = 1 means the model give Best Prediction,
BSS = 0 means the model is matching the baseline condition.
Negative values will indicate that the model predictions are moving away from the measured conditions (Sutherland *et al.*, 2004).

RESULTS AND DISCUSSION

To apply the statistical use in the evaluation of a numerical model, one case study has been carried out by Awang (2010) at Sungai Haji Dorani, Peninsular Malaysia. The 3DD Modelling Software developed by ASR Limited was used in the case study to assess the site suitability for mangrove replanting. The MAE and BSS methods (as explained above) were then used where the model's results were calibrated and validated against the measured data to facilitate an accurate representation of the study area, thus provide high level of confidence in the model.

Sungai Haji Dorani (as shown in Figure 1) is a low gradient muddy shoreline, consisting predominantly of silt and clay, over which occurs a fluid mud layer in range of 0.3 to 0.5 m thick (Awang, 2010). The existing mangrove belt is very narrow likely to be less than 20 m width with no natural mangrove regeneration to replace the mangroves lost due to the natural processes and coastal development. As mangroves cannot simply grow anywhere, using numerical models can give some confidence for the project success with some hind-cast statistics. Beside it is well-known as prediction tool to identify suitable areas for very wide space areas. Another benefit on these numerical modelling is that even after validation, the developed model can be used for different scenarios as required. Fig. 1. shows the cumulative mass of TSS, TP, TN, AN, NOx removed from each columns over 7 days of dosing. Fig. 2 compares the influent and effluent concentrations for columns containing different types of bioretention media. It was found that clogging occurred in columns NP and CS after day 4 of the experiment. Hence, only results for columns PP and CH will be shown in Fig. 1. and Fig. 2 for comparison with standard column (SC).

For this purpose, a data collection campaign was carried out from 8 to 30 January 2009, to obtain the measured data at the study location. Some equipment was installed to accomplish the bathymetric survey, tidal fluctuation, water quality, current and wave profiling and sediment sampling i.e. Aquadopp Current Profiler (ADCP), echo-sounder, Fugro OmniSTAR Differential Global Positioning System (DGPS), OBS-3A and Tide Gauge. The location of the equipment installed is shown in Figure 2.

Based on the objectives that have been set for the modelling study, a numerical model with 200m grid resolution was developed and simulated for the study area. The boundary conditions for water levels used were from Bagan Datoh, Malaysia in the North and Tanjung Sinaboi, Indonesia in the South (Awang, 2010). The simulation period was 572 hours which is equivalents to 23.8 days to cover the measured data from 8 to 30 January 2009. Calibration on the water level elevations at Sungai Selangor, Pintu Gedong and Haji Dorani using MAE and BSS methods show that the model results give BSS values ranged between 0.73 and 0.95 (see Figure 3). Using the same methods for validation on the current characteristics at Station 1 and 2 resulted in BSS values of between 0.6 and 0.84 for current speed and direction (see Figure 4). Since this numerical model gives quite an accurate representation of the study area, further analysis can be carried out on the model results to evaluate the suitability of the proposed mangrove replanting site.

Model results show that the peak current speed in the Straits of Malacca during the spring flood tide is more than 1.5 m/s (see Figure 5A) while the peak current speed during the spring ebb tide is greater than 0.5 m/s (see Figure 5B). During the neap flood tide, the peak current speed in the Straits of Malacca is about 0.8 m/s (see Figure SC)while the peak current speed during the neap ebb tide is about 0.4 m/s (see Figure 5D). Zooming into Haji Dorani coast, the peak current speed during the neap and spring tide ranged from 0 to 0.4 m/s and higher velocities occur offshore (i.e. 0.5 to 1.4 m/s).

Analysis of the mean residual circulation within the Straits of Malacca shows that the current speeds are greater than 0.3 m/s, high enough to transport sand (see Figure 5) while Haji Dorani coast experienced a mean residual velocity higher than 0.04 m/s (see Figure 6), which is high enough to transport silt and clay that is already suspended. The result indicates that silt and clay particles will not be deposited permanently as they may be re-suspended and transported away from the study area.

Allen (1985) had stipulated that the particle fall velocities for fine sand, silt and clay are 0.001; 0.0001; and 0.000001 m/s, respectively. In muddy areas, flocculation processes will normally occur, incorporating clay particles dependent on the electrostatic stability of the suspended particles and suspended sediment concentration (Wolanski, 1995). However, flocculation of mud will not happen in areas with current velocities of more than 0.4 m/s as the flocculants (clay and silt) will disintegrate when tidal velocity is higher than 0.1 m/s due to the weak chemical bond. Therefore, although the current speeds around Haji Dorani coast ranged between 0 and 0.4 m/s, flocculation of mud will not happen since the velocities are higher than the particle fall velocities for silt and clay. As the results, most of the mud at Sungai Haji Dorani will be suspended and re-suspended in the water column because no deposition of substrate will occur. This condition will not promote establishment of mangroves as mangroves need stable substrate for its roots to hold on. A suitable structure will need to be constructed to help dampen the current velocities to promote deposition of substrate.

Figure 1. Location of Sungai Haji Dorani situated on the West coast of Peninsular Malaysia.

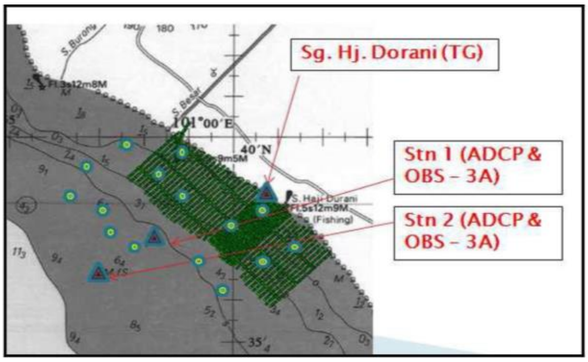

Figure 2. Map of Sungai Haji Dorani showing the location of the instruments deployed.Yellow dots (circles) indicate the grab samples location while green dots/lines indicate the extent of the bathymetric survey.

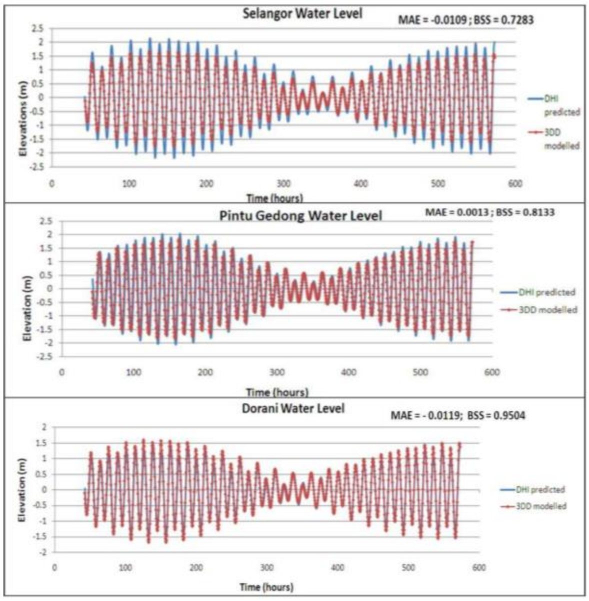

Figure 3. Calibration of water levels at Sungai Selangor (above), Pintu Gedong (middle) and Dorani (bottom).

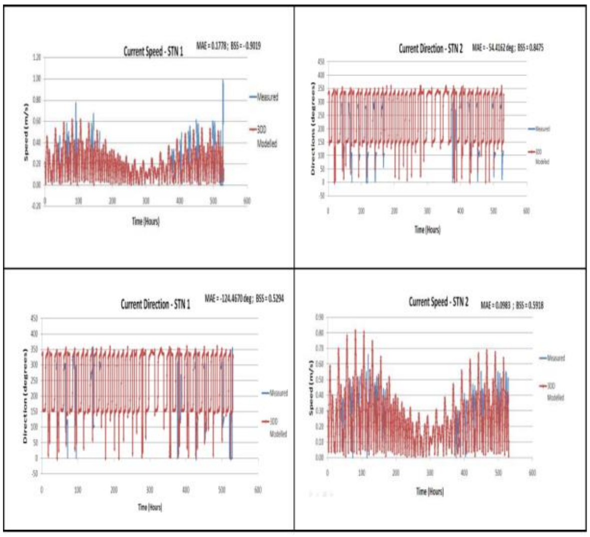

Figure 4. Validation of current speed (left) and current direction (right) at both Station 1 and 2.

CONCLUSIONS

As many benefits from the statistical analysis applied in the numerical model for this study, it gives a high agreement between the model results and the measured data. The MAE and BSS methods had been successfully applied in the numerical model for mangrove replanting, and show that the numerical model results are in good performances as the BSS ranged from 0.73 to 0.95 for the water level elevations and 0.6 to 0.84 for current characteristics. Thus, it is confident to say that current velocities around Sungai Haji Dorani varies between 0 — 0.4 m/s, high enough to erode sand particles. Therefore, Sungai Haji Dorani is not a suitable site for mangrove replanting unless an appropriate structure is constructed to dampen the current velocities.

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