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EFFECTS OF HYDROKINETIC ENERGY TURBINE ARRAYS ON SEDIMENT TRANSPORT AT SÃO MARCOS BAY, BRAZIL

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1. Introduction

At the present time, the role of renewable energy in Brazil is significant as hydropower and other renewable energies, mainly biomass, contribute with 70.7% and 9.6%, respectively, towards the total offer for electric energy, as compared to the corresponding figures of 14.8% and 5.6% regarding worldwide averages (MME, 2014). Nevertheless, there is already an increasing role which is played by wind energy, and a promising potential for tidal current energy.

2. Objectives

This paper is concerned with the assessment of the tidal current resource in São Marcos Bay, located on the north-eastern coast of Brazil in the state of Maranhão (Figure 1), and possesses a highly promising potential for the generation of electricity through the conversion of tidal current energy. Also, the impact of in-stream Hydrokinetic Energy Turbine (HET) arrays would have on the bay's morphology is studied.

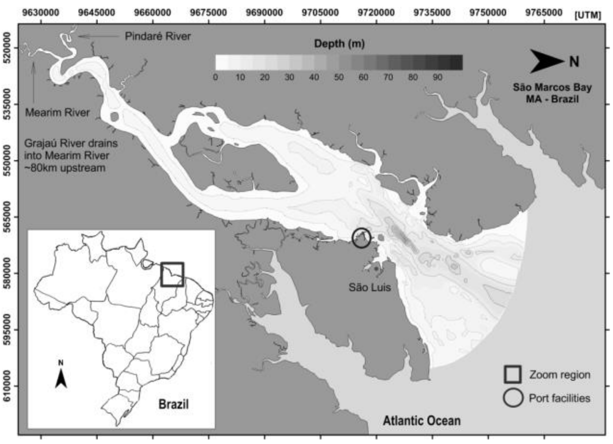

Figure 1. Baía de São Marcos and region of study.

3. Methodology and results

Three potential zones for tidal power exploitation have been identified, Figure 2, employing SisBaHiA® finite element hydro-sedimentological model (Rosman, 2015) based on the sediment transport equation of Engelund & Hansen (1967). Potential zones have surface areas of 1 km² to 5 km², mean spring peak tidal currents in the range of 2–2.7 m/s and water depths range from 22 m to 40 m.

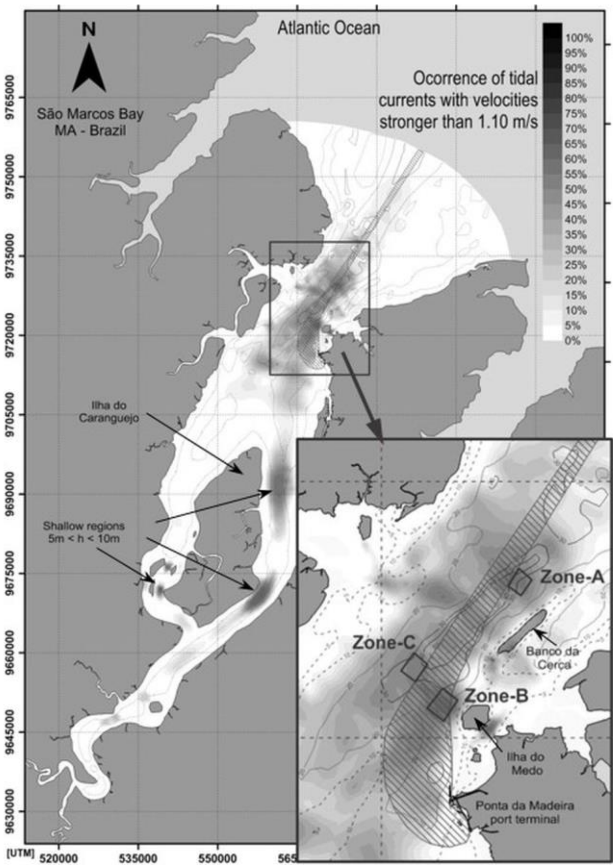

Figure 2. Hot spots for efficient tidal current power extraction in São Marcos Bay. Zoom region shows bathymetry contours.

An analytical power model applied for each zone defines HET array characteristics and demonstrates an annually potential output in the range of 34-49 GWh. The analytical power model has, for simplification, a fix lateral spacing between HETs set in 3 rotor diameters and considers cut-in and cut-off velocities. Table 1 summarizes HET arrays characteristics for each zone.

Zone	Diameter D_R of rotor (m)	Δx (m)	Nº of HETs per row	Nº of rows	Generated Power (GWh/ano)
A	20	400	16	3	49.0
B	15	450	25	3	41.0
C	20	400	14	3	34.0

Table 1. HET array characteristics for each zone.

An additional stress term, Equation (2), has been added to the model momentum equations, Equation (1), in order to include HET operation as a momentum sink, taking into account thrust coefficient.

$$\frac{\partial \hat{u}_i}{\partial t} + \hat{u}_j \frac{\partial \hat{u}_i}{\partial x_j} = -g \frac{\partial \zeta}{\partial x_i} + + \frac{1}{\rho H}\left[\frac{1}{\partial x_i}\left(\underset{1*}{H\,\hat{\tau}_{ij}}\right) + \underset{2*}{\tau_i^S} + \underset{3*}{\tau_i^F} + \underset{4*}{\tau_i^T}\right] + \hat{a}_i \quad (1)$$

where $z = \zeta\,(x, y, t)$ stands for the free surface elevation, $z = -h\,(x, y, t)$ for the bottom bathymetry, and $\hat{u}_i$, for the depth averaged velocity in the i-th direction. In models with fixed bathymetry, h is time–independent. Here $H = \zeta + h$ stands for the local water column height, $\hat{a}_i$, represents the Coriolis acceleration term, 1* are depth averaged turbulent shear stresses, 2* and 3* stands for shear stresses in the i-th direction and at the free surface and at the bottom, respectively. Finally, 4* stands for the turbine stress term added in order to account for the head losses due to the influence of TEC. The turbine stress term is expressed as:

$$\tau_i^T = \frac{1}{2}\rho C_T \left(\hat{u}^2 + \hat{v}^2\right)^{0.5} \hat{u}_i \cdot \Theta \quad (2)$$

C_T represents the thrust coefficient, which is related to the power coefficient, C_P, through the linear momentum actuator disk theory in an open channel developed by Houlsby et al., (2008), and based on the work of Rankine (1865) and Froude (1889). If A_T is the swept area of a TEC, A_I is the area of influence of each computational node, and NT is the number of turbines per computational node, then,

$$\Theta = N_P . \left(A_T / A_I\right) \quad (3)$$

which represents the total swept area per computational node, is known as nodal blockage. Then the power available for a TEC is:

$$P = 0.5 \rho C_P A_T U^3 \quad (4)$$

Six scenarios with full-scale HET arrays are modelled to study hydrodynamic influences between arrays, as well as morphological effects. During simulations a constant thrust coefficient of 0.54 (Fraenkel 2009) is maintained. The hydrosedimentological scenarios include, initially, a simulation without HET arrays to adjust bathymetry of possible data uncertainties to an equilibrium condition, afterward individual simulations of each array, followed by pairs of arrays. Even though, the sediment transport model accepts differentiating granulometry and erosion limit at each calculating node of the domain, it was adopted a uniform granulometry consisting of five types of sediments distributed in an erodible layer of up to 5 m. Results for the hydrodynamic interference study indicate gains and losses in power output up to 16.7 % and 10.7 % respectively, see Table 2. Morphological effects are studied in the proximities of the promising zones. Results, interpreted in a qualitative manner, indicate the formation of sand banks with heights lower than 0.75 m and regions experiencing levels of erosion of the same order.

Zone	**Percent of power density gain (+) or loss (-) due to array interference for HET arrays**					
	A	**B**	**C**	**A-B**	**A-C**	**B-C**
A	---	3.2	-5.4	---	---	-10.7
B	-2.5	---	9.5	---	-10.4	---
C	-4.1	16.7	---	13.2	---	---

Table 2. Percent of power density gain (+) or loss (-) due to array interference.

4. Conclusions

The study concludes that there are large amounts of tidal energy available at São Marcos Bay Future that can be transformed to electricity using HETs. Nevertheless, it has been confirmed that HET arrays influenced erosion and deposition rates of regions up to a distance of 15 km. Future work is directed towards layout optimisation to maximise electric energy generation (Gorbeña et al., 2015), minimising adverse effects in sediment dynamics.

Acknowledgments

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