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IMPACTS OF TIDAL-STREAM ENERGY CONVERTER (TEC) ARRAYS IN RELATION TO THE NATURAL VARIABILITY OF SEDIMENTARY PROCESSES

Peter E. Robins[1], Simon P. Neill and Matt J. Lewis
School of Ocean Sciences,
Bangor University, UK. LL59 5AB

ABSTRACT

Tidal-stream Energy Converter (TEC) arrays are expected to reduce tidal current speeds locally, thus impacting sedimentary processes, even when devices are positioned above bedrock. Tidal dissipation can produce high suspended sediment concentrations (turbidity maxima) which are important for biological productivity. Also, devices will potentially impact morphological features further afield, e.g., offshore sand banks and beaches.

Yet few impact assessment studies of potential TEC sites have looked closely at sediment dynamics beyond local scouring issues. It is therefore important to understand to what extent exploitation of the tidal energy resource will affect sedimentary processes, and the aim of this research is to assess the scale of this impact in relation to natural variability, caused by both tidal currents and wave-induced currents.

INTRODUCTION

With growing interest in the exploitation of the tidal energy resource, the environmental impact requires further investigation [1-3]. Tidal-stream turbines will reduce velocities and so impact sediment transport [2]. One way to ascertain whether these environmental impacts are within the 'acceptable' range is to evaluate the intra-seasonal and inter-annual variability due to tidal and wave motions [4,5]. Wave-induced variability will be greater during winter [6], when energy demand is high, than during summer when the sea is rich with biological productivity [7]. To date, this approach has not been adopted in such environmental impact assessments [1,8].

Strong tidal dissipation can generate turbidity maxima - regions of high concentrations of suspended material [9] which are important as they enhance nutrient supply for economically important species [10,11]. Turbidity maxima mediate marine population dynamics [12]; hence, the effect of TEC arrays on the turbidity maxima is of obvious concern.

Bed load transport mediates coastal morphology and sediment supply to beaches and off-shore sand banks. Sand banks form in the lee of strong flow, maintained by recirculating tidal flows forming large eddy systems [13]. Sand banks are important for natural coastal protection during storm events as they cause waves to refract and dissipate their energy [1]. It is important that the sedimentary processes described above are understood, and their natural variability quantified, if we are to assess the potential impact incurred by tidal-stream energy extraction.

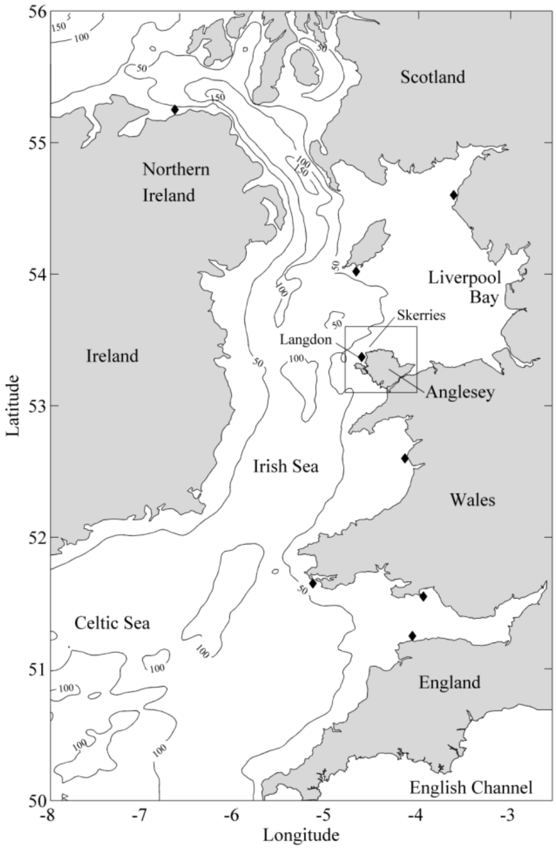

Figure 1. The Irish Sea, showing water depths (m, relative to MSL). We focus on sedimentary processes around northwest Anglesey (boxed area), where we have conducted two in situ surveys and also simulated tidal-stream energy extraction. Our model was validated against tide gauge stations around the Irish Sea (marked with diamonds).

METHODOLOGY

At one location off the northwest coast of Wales in the Irish Sea (Fig. 1), that is highly attractive for the deployment of TEC arrays due to strong tidal currents, we conduct several field surveys to measure the circulation patterns, the suspended sediment concentration (the 'Anglesey Turbidity Maximum' which forms here is the largest turbidity maxima in the Irish Sea), bedload sediment types, and high resolution bathymetric data.

We apply and validate a high resolution unstructured morphodynamic ocean model (Telemac Modelling System; v6.2 [14]) over the Irish Sea domain shown in Fig. 1. Wave climate simulations of the northwest European shelf seas, over a 7 year period using a validated spectral wave model (SWAN; [6]), were also performed in conjunction with the morphodynamic model in order to quantify the natural variability in bed shear stress due to combined tidal and wave conditions [15]. We then simulate the impacts of several tidal-stream energy extraction scenarios using the morphodynamic model.

RESULTS

SWAN simulated wave-induced bed shear stress at the TEC site was 0.012 ± 0.005 N m^{-2} (Fig. 2a). Intra-seasonal variance, however, was greater (Fig. 2b). At Langdon sand bank, 10 km to the southwest of the TEC site, wave-induced bed shear stress was greater than at the TEC site, since water depths are reduced (Figs. 2c and 2d). Yet total bed shear stress was dominated by the tidal forcing; averaged tidally-induced bed shear stress was 5.24 N m^{-2} (at the TEC site) and 3.39 N m^{-2} (at Langdon sand bank), simulated using the morphodynamic model.

In order to assess the scale of the impacts of energy extraction on bed shear stress, we have considered natural intra-seasonal and inter-annual variability of bed shear stress (Fig. 3). Total seasonally-averaged (for 'summer' and 'winter') bed shear stress, due to combined tidal and wave motions, is plotted for the present-day natural case and for different energy extraction scenarios (i.e. extracting 10-500 MW). The maximum seasonal variance has enabled us to calculate the threshold of energy extraction that reduces bed shear stress significantly. Our results show that, during winter months, up to 165 MW can be extracted by the TEC array before local impact on bed shear stress exceeds natural variability (Fig. 3a). During summer, this threshold is reduced to 85 MW (Fig. 3b). The regional impact of energy extraction is likely to be insignificant with regard to natural variability (Figs. 3c and 3d).

CONCLUSIONS

A 2D, finite-element morphodynamic model has been used to simulate complex sedimentary processes in a region which is desirable for tidal-stream energy extraction (northwest Anglesey, UK). Simulated energy extraction at this site has shown that first generation TEC arrays (of the order 10-50 MW) reduce velocities locally by only a few per cent, and reduce bed shear stress and bed load transport by slightly more (suspended load transport is relatively unchanged, since TEC arrays induce locally increased turbidity). However, these changes were small compared to the range of natural variability and could therefore be considered negligible. It is only when a considerable proportion of energy was extracted from the system (e.g. greater than 50 MW) that sedimentary processes became significantly affected. Further afield (e.g. 10 km from the TEC array), it is unlikely that the impact of energy extraction on bed shear stress will ever exceed natural levels of variability, in all but the most quiescent wave periods, and most energetic (spring) tidal periods.

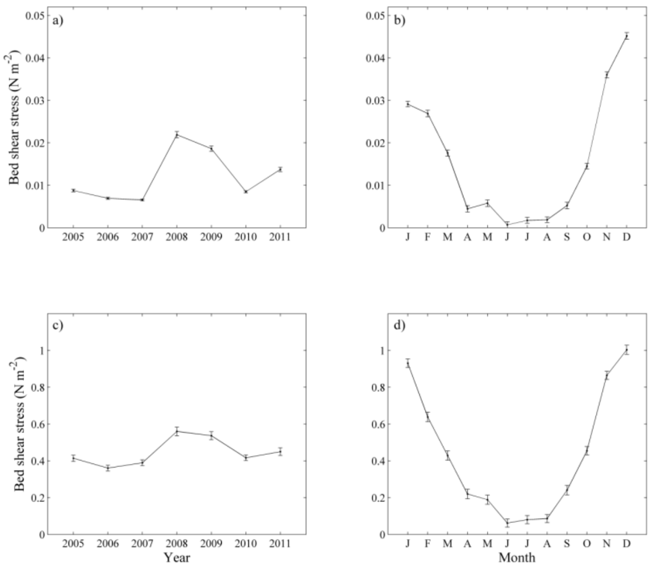

Figure 2. Natural variability in wave-induced bed shear stress: at the Skerries (a, b) and at Langdon sand bank (c, d). Inter-annual (a, c) and intra-seasonal (b, d) variabilities of the wave climate are shown, where error bars denote 95% confidence intervals.

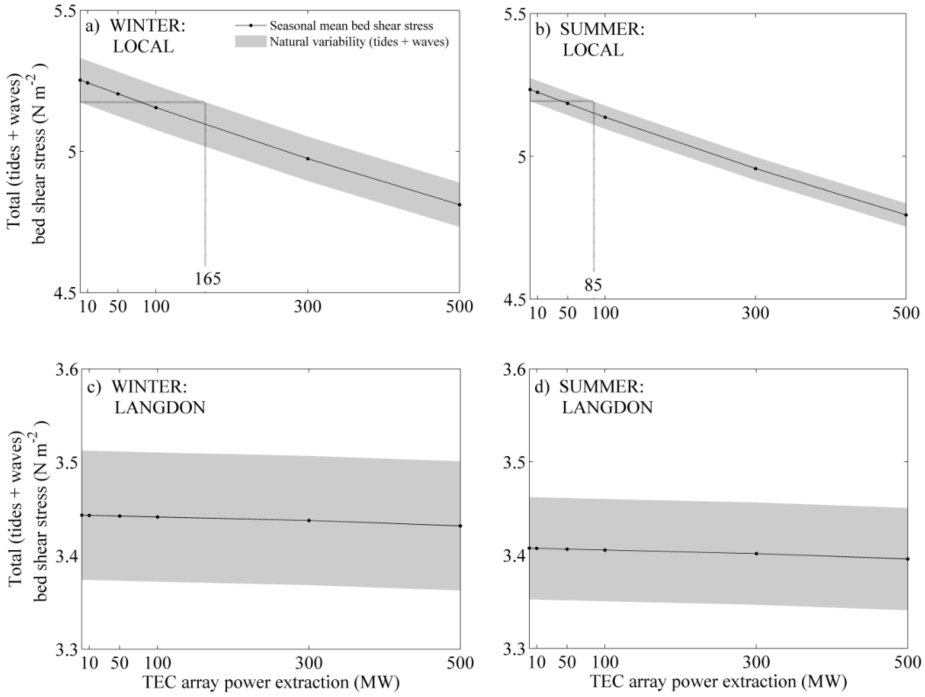

Figure 3. Impact of energy extraction, from simulated TEC arrays at NW Anglesey, on total (tides + waves) bed shear stress. Results are shown at the point of energy extraction (a and b) and at a sand bank 10 km further afield (c and d). Bed shear stress during winter (a and c) has been plotted separately to summer (b and d). Natural variance in total bed shear stress (shaded areas) denote one standard deviation either side of the seasonal mean. Dotted lines (in a and b only) show the threshold of energy extraction where impact of the TEC arrays exceeds natural variability.

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