Impact of tidal energy arrays located in regions of tidal asymmetry

Simon P. Neill
School of Ocean Sciences, Bangor University, Menai Bridge LL59 5AB

Summary: Tidal stream turbines are exploited in regions of high tidal currents. Such energy extraction will alter the regional hydrodynamics, analogous to increasing the bed friction in the region of extraction. In addition, this study demonstrates that energy extracted with respect to tidal asymmetries due to interactions between quarter (M4) and semi-diurnal (M2) currents will have important implications for large-scale sediment dynamics. Model simulations show that energy extracted from regions of strong tidal asymmetry will have a much more pronounced effect on sediment dynamics than energy extracted from regions of tidal symmetry. This has practical application to many areas surrounding the UK, including the Irish Sea and the Bristol Channel, that exhibit strong tidal currents suitable for exploitation of the tidal stream resource, but where large variations in tidal asymmetry occur.

Introduction

The phase relationship between the M2 and M4 tidal currents can lead to asymmetry [1]. Although the combination of M2 and M4 tidal currents in Fig. 1a results in a distorted tide (Fig. 1b), the flood and ebb tides are equal in magnitude, as is the bed shear stress (based here on the assumption of a quadratic friction law). Hence, there is no residual sediment transport. By combining M2 and M4 tidal currents as in Fig. 2a, however, the flood tide is stronger than the ebb (Fig. 2b). Although there is no net residual flow, the integrated square of the velocity (U^2) is greater during the flood. Hence, there is a residual bed stress and the net direction of sediment transport will be in the flood direction. In the context of marine renewable energy, the question then arises, "how will changes to the sediment dynamics, and resulting morphodynamics, vary between a tidal stream array sited in a region of strong tidal asymmetry, and a tidal stream array sited in a region of tidal symmetry?"

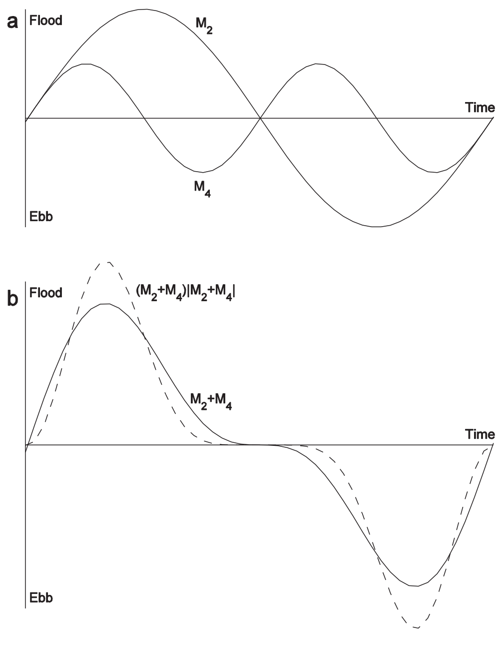

Fig. 1. Combination of M2 and M4 tidal currents resulting in tidal *symmetry*. (a) Tidal currents for individual constituents and (b) tidal currents (solid line) and bed stress (dashed line) resulting from superposition of M2 and M4 constituents.

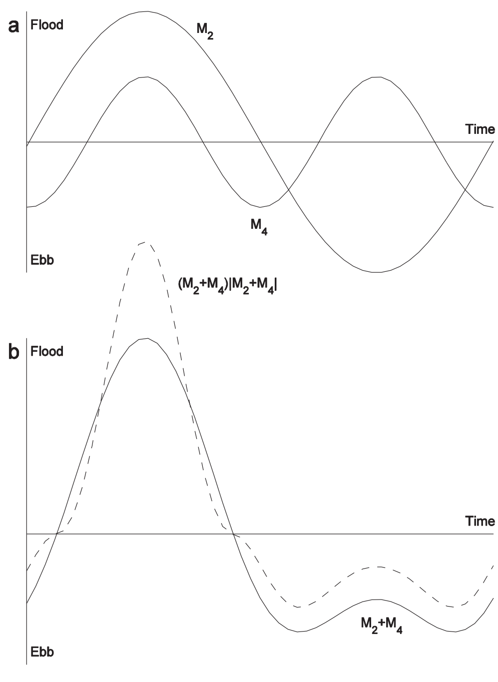

Fig. 2. Combination of M2 and M4 tidal currents resulting in tidal *asymmetry*. (a) Tidal currents for individual constituents and (b) tidal currents (solid line) and bed stress (dashed line) resulting from superposition of M2 and M4 constituents.

Methods

A one-dimensional morphological model was developed and applied to a case study (the Bristol Channel) where large spatial variations in tidal asymmetry occur along the length of the channel. The morphological model consisted of three components: hydrodynamic, sediment transport and bed level change models [2]. An energy extraction term was incorporated into the hydrodynamic model, with power extracted as a function of U^3. The idealised power and power coefficient curves were based on a MCT 'Seagen' device [3]. The model was applied to the entire length of the Bristol Channel for a duration of 29.53 days (a lunar month), and the output for various energy extraction scenarios compared to the natural case.

Results

The model results demonstrate that, regardless of the location of energy extraction, the magnitude of bed level change is dampened by the presence of a tidal stream farm (due to a general reduction in tidal velocity and hence net sediment transport). However, the location of energy extraction is important with regard to the magnitude of bed level change based on two main criteria: the magnitude of sediment transport at the point of extraction, and the degree of tidal asymmetry at the point of extraction. The first criterion is obvious, so the bed level change results were normalised by the gross mean sediment transport at the point of energy extraction, averaged over the duration of the simulation to remove the effect of longitudinal variations in the magnitude of sediment transport at the point of energy extraction. The main finding is that when energy is extracted from a region of strong tidal asymmetry, the effect on the resulting bed level change is more pronounced (up to 29% difference from the natural tidal channel case) compared with energy extracted from regions of tidal symmetry (18% difference).

Conclusions

A one-dimensional numerical model has demonstrated that a small amount of energy extracted from a tidal system can lead to a significant impact on the sediment dynamics, depending on tidal asymmetry at the point of extraction. The resulting influence on the morphodynamics is not confined to the immediate vicinity of the tidal stream farm, as would occur in the case of localised scour, but affects the erosion/deposition pattern over a considerable distance from the point of energy extraction (of order 50 km in the case of the Bristol Channel). However, regardless of the location of a tidal stream farm within the tidal system, energy extraction reduces the overall magnitude of bed level change in comparison with non-extraction cases. Therefore, when considering the environmental impact of a large-scale tidal stream farm, it is important to consider the degree of tidal asymmetry in addition to the local magnitude of tidal currents at the point of energy extraction.

References:

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