Feedbacks between energy extraction and bed elevation morphodynamic

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Summary: Anticipating the effect of tidal energy extraction on tidal basin morphodynamic over decadal time scales is required for coastal management purposes and commercial development planning over the useful life of the plant. Causal loop analysis is used here to explore the influence of tidal energy extraction on bed elevation morphodynamic. This qualitative analysis, suggested that erosion-deposition balances of weakly coupled bed sediments (i.e. coarse bed material or low energy environments) are the most affected by reducing the resilience (i.e. ability to return to original state of water depth) or even de-coupling it from hydrodynamic forcing.

Introduction

Natural variability and estimations of morphology changes with and without tidal energy extraction has been used to assess the importance of tidal energy extraction on bottom morphodynamic and sediment transport [1,2]. [1] conclude that energy extraction (of the order 10-20 MW) will reduce velocities and suspended sediment concentrations locally but considered these changes negligible for being an order of magnitude less than seasonal predicted variability. [2] Using model simulations suggested that the influence of tidal energy extraction on bed level change is more pronounced on regions of strong tidal asymmetry by affecting the erosion/deposition pattern over a considerable distance from the point of energy extraction. Extrapolating these results to decadal morphodynamic behaviour at basin scale is not trivial due to non-linarites and the lack of an up-scaling closure theory. Recently it has been shown how causal loop analysis can be used to assess the coastal system behaviour at decadal and longer time scales [3]. This method of analysis is used here to explore the impact of tidal energy extraction on the erosion-deposition balance.

Methods

First Causal Loop Diagrams are used to represent a distillation, from existing literature, of the feedback structure (at active layer scale) of a non-specific tidal basin system (Figure 1). Then, the influence of tidal energy extraction is included into the feedback structure and qualitative stability diagrams used to assess the system behaviour. To be consistent with the [1, 2], tidal energy extraction is conceptualized here as an extra energy dissipation process that varies non-linearly with the flow velocity. The energy extraction is represented as a positive link between the local depth-averaged wave-tides induced current velocity and the tidal energy extraction rate (Figure 1a). A positive influence indicates that an increase of current velocity increases the tidal energy extraction rate. To avoid cluttering the feedback structure this positive link is collapsed (i.e. product of positive and negative links) as a negative link between the local water depth (h) and the energy extraction rate. In contrast to wave and current energy dissipation rate due to bottom friction, tidal energy extraction rate has a negative influence on the erosion rate by reducing the near bed erosion potential. This is derived from the depth-averaged energy conservation and suspension model of [4]. Tidal energy extraction adds a new energy dissipation process to the energy balance indirectly reducing the sediment suspension efficiency. This difference introduces a new reinforcing feedback loop into the system that competes with the natural balanced erosion-deposition feedback loop (Figure 1b, blue and green loops respectively).

Results

Figure 2 illustrates three potential types of influences on the local erosion-deposition balances; (a) if the bed layer is not coupled with the hydrodynamic it will remains non-coupled if tidal energy is extracted; (b) if original stable and non-stable water depth are not well apart, tidal energy extraction might either reduce this distance further or even decoupling the bed from the hydrodynamics; (c) if the bed layer is coupled and the water depth at which unstable and non-stable erosion/deposition balances lies are well apart, the new depths will be only slightly modified.

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Conclusions

Impacts of tidal energy extraction on bed layer dynamic are explored by reasoning on the feedback loop structure of morphodynamic processes at the active layer scale. It is shown how non direct effect are triggered influencing the overall feedback factor balance by adding a new reinforcing loop. Erosion-deposition balances of weakly coupled bed sediments (i.e. coarse bed material or low energy environments) are the most affected by reducing the resilience (i.e. ability to return to original state of water depth) or even de-coupling it from hydrodynamic forcing.

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References:

[1] Robins, P. E. (2013). Influence of tidal energy extraction on fine sediment dynamics. *Proc. 2^{nd} Oxford Tidal Energy Workshop*, Oxford, UK, pp 27-28.

[2] Neill, S. P. (2013). Impact of tidal energy arrays located in regions of tidal asymmetry. *Proc. 2^{nd} Oxford Tidal Energy Workshop*, Oxford, UK, pp 19-20.

[3] Payo, A., Hall, J., French, J., Sutherland, J., Maanen, B., Nicholls, R. J., Reeve, D. (in press). Causal loop analysis of geomorphological coastal systems. Special issue *Journal of Geomorphology*.

[4] Kobayashi, N., A. Payo, and L. Schmied, Cross-shore suspended sand and bed load transport on beaches. *Journal of Geophysical Research*: Oceans, 2008. 113(C7): p. C07001.

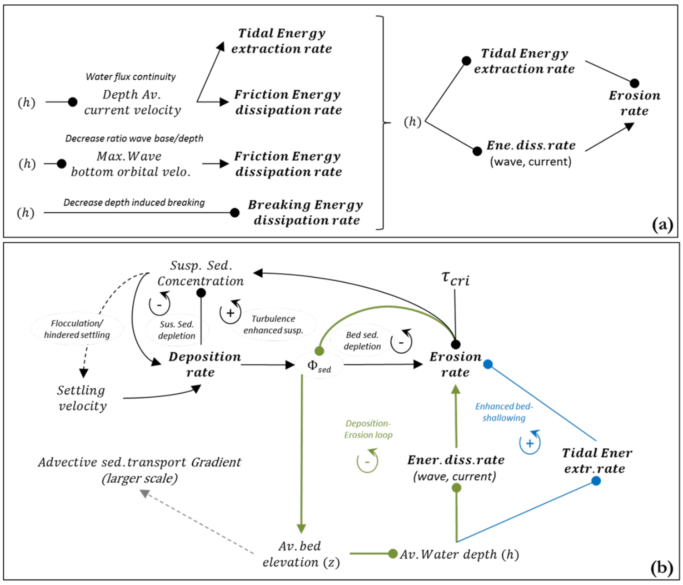

Figure 1. Tidal energy extraction within the feedback structure of tidal basin morphodynamic processes at the active layer scale. State variables are represented by text and positive/negative links between them as arrow or dot headed lines. The position of the line head represents the polarity of the link. Tidal energy extraction is represented as a positive link between the depth-averaged velocity and energy extraction (a). The influence of tidal energy extraction is collapsed into a negative link between average water depth and Energy dissipation rate. The overall feedback structure is represented in (b). Influence on local bed elevation on advective sediment transport is acknowledge but not represented (larger scale).

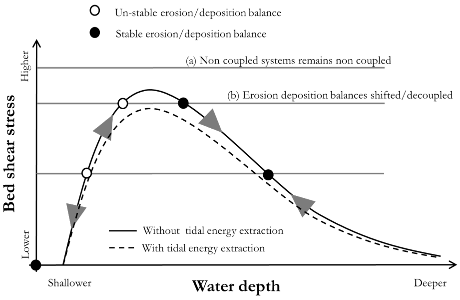

Figure 2. Anticipated influences of tidal extraction on the local erosion/deposition balance. The mean variation of bed shear stress due to wind and waves with the water depth is represented as a black curve. A dashed black curve represents the bed shear stress if tidal energy extraction is included. Noticed that due to non-linearity higher bed-shear stress are significantly more reduced than lower values. The critical shear stress needed to initiate sediment transport is presented by three horizontal grey lines. If critical shear stress crosses the bed shear stress curve, bed changes are coupled with hydrodynamic. When coupled, two stable and one unstable erosion/deposition balance might occur. The arrows indicate the direction of change.