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The effects of tidal farms in estuaries under extreme coastal and fluvial events

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Summary: This study investigates how tidal farms interact with coastal and fluvial flooding events in estuaries. A numerical model of the Solway Firth has been developed to identify the changes in the maximum water levels. Two different farm layouts have been introduced in order to compare their effects and extracted power. As a conclusion, the results are positive in terms of the flood risk in both cases while the parallel layout turns out to give a better performance in relation to the energy extraction.

Introduction

Estuaries represent a high resource of tidal energy in the UK and they also benefit of being more accessible for the installation of tidal farms than offshore locations. On the other hand, being a transition between the rivers and the open sea, their hydrodynamic behaviour is highly complex. Besides, there is a probability of extreme events happening in these areas with damages to the associated assets and environment. This study aims to give a better understanding of the interaction that large groups of tidal turbines could have in estuaries under the combination of coastal and fluvial flooding events.

Methods

The Solway Firth estuary, located between Cumbria and Dumfries and Galloway, was selected as a real case study from a group of estuaries with a high resource of tidal energy in the UK. There is a high current speed (up to 2 m/s) at some locations and there is significant risk of flooding.

A numerical model (Mike 21 by DHI) was used to reproduce the hydrodynamic conditions in the Solway Firth under the extreme events. A more detailed description of the software can be found in DHI, 2005 [1]. A summary of the main features of the model is presented in Figure 1. A broader description of the parameters involved, the calibration of the model and the data sources can be found in Garcia-Oliva et al., 2014 [2].

The boundary conditions in the model were mainly defined by the water levels at the open sea and the discharge from the rivers flowing into the estuary. Three different scenarios were used to cover a combination of events under normal and extreme conditions. In the first scenario, boundary conditions consisted of the 200-year return period event happening at the open sea, formed by storm surge and the highest astronomical tide, and the average discharges of the rivers, as explained in Garcia-Oliva et al., 2014 [2]. In the second scenario, boundary conditions at the open sea consisted of the tidal elevations, given by the Global Tide Model by means of the Mike 21 toolbox for the prediction of tidal heights. The river discharges were related to the values for the 200-year return period event provided by the CEH (Centre for Ecology and Hydrology) according to the procedures in Morris, 2003 [3]. Finally, the third scenario was a combination of the aforementioned cases.

A tidal farm consisting of 32x32 turbines was introduced in the model at the area with highest current velocities and a suitable depth. Turbines are defined by a drag force component directly included in the governing equations. The turbine dimensions are based on the MRL design (Momentum Reversal Lift), described by Gebreslassie et al., 2013 [4]. This design can be installed in shallow estuaries because the diameter is smaller than the one in axial flow designs. A description of the turbine parameters in the model can be found in Garcia-Oliva et al., 2014 [2]. Two different layouts, parallel and staggered, were used to analyse the effects that the geometry of the farm could have on the hydrodynamics and the extracted power. The spacing between the turbines is the same in both configurations, namely lateral spacing of 85.8 m and longitudinal distance of 124.8 m. The numerical mesh was refined in the area of the tidal farm with the use of rectangular elements including each turbine. (Figure 4)

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Results

Only the results for the third scenario are provided in this document as it represents the worst situation. Figure 2 shows the main values for the differences between the maximum water levels in the situation with and without tidal farms (Δh_M) and the total mean and peak extracted power by each tidal farm. A statistical analysis tool in Mike21 provided the maximum values of the water levels. The mean extracted power was obtained as the sum of the results (product of drag force and incident flow speed) from all turbines and time steps and averaged over the period of the simulation (14 hours), being the peak power the maximum value for the farm from all time steps.

Conclusions

The effects of both configurations in the maximum water levels are very similar, resulting in a decrease of the order of cm at the inner part of the estuary and an increase of the order of mm in the rest of the estuary, as can be seen from Figure 3. On the other hand, the parallel layout would imply a higher extracted power than the staggered layout. However, it would be necessary to undertake further research regarding the use of different spacing in the farm and a drag coefficient obtained through experimental testing of the MRL turbine.

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References:

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Simulation Period	100 h
Time step	900 seconds
Number of elements	14266 (parallel), 15910 (staggered)
Maximum mesh Size	1 km^2
Bed roughness (1/n)	22 $m^{1/3}/s$
Smagorinsky's coeff.	0.28

Figure 1. Model features

Results		*Scenario c*	
		Parallel	*Staggered*
Δh_M (m)	**Max. Increase**	0.004	0.004
	Max. Decrease	0.064	0.063
Mean Extracted Power (MW)		58.39	57.49
Peak Extracted Power (MW)		179.00	176.49

Figure 2. Model results for the worst case scenario

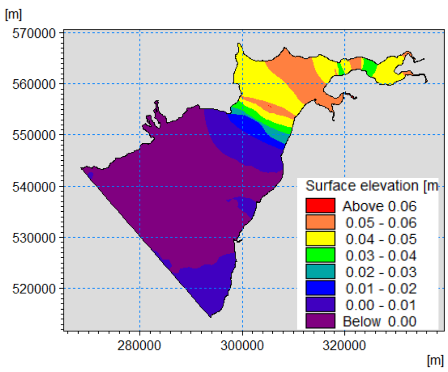

Figure 3. Difference in maximum water levels

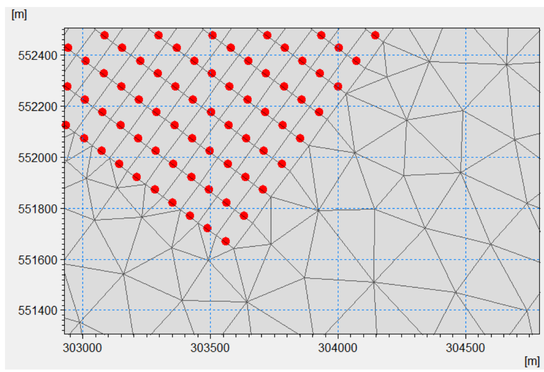

Figure 4. Computational grid refinement