Numerical modelling of sea bed morphodynamics associated with tidal energy extraction

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Summary: Tidal energy generation is an option favoured by the UK Government towards its initiative to generate renewable energy. Since the industry is now moving toward - tidal array devices deployments, it is important to investigate environmental impacts associated with tidal energy extraction. As a result, it is essential that a good understanding is gained upon altered residual flows connected to sediment transport regime and perturbed vertical velocity profiles controlling sediments in suspension, and effects of tidal array installations on sea bed sedimentary features, before reaching commercialization [1]. In the present study Delft3D coastal area morphodynamic modelling suite is used to investigate hydrodynamic and in subsequent morphodynamic aspects of tidal energy extraction. Initial results indicate that morphodynamics in areas considered for tidal turbines deployment are in a dynamic equilibrium. In such a dynamic environment, results imply that possible alterations in tidal currents due to energy extraction may have some implications on existing morphodynamic regime.

Introduction

UK is ideally located to exploit marine renewable energy resources. Tidal energy generation is an option favoured by the UK Government [2]. It is thus vital that local and regional environmental impacts of tidal energy extraction are well understood. However, potential impacts that arrays of tidal current turbines may have on the surrounding coastal environment is still largely unknown. Particular concerns are the extent to which the altered tidal environment as a result of energy extraction will change the natural sediment transport regime and hence the sea bottom morphodynamics, which may have some implications on the stability of nearby beaches and sea bed ecology [3].

In the work presented here, Delft3D coastal area morphodynamic modelling suite is used to investigate hydrodynamic and morphodynamic aspects of tidal energy extraction. Pentland Firth (PF) channel between Scottish Mainland (UK) and Orkney Islands, joining Atlantic Ocean with the Northern Sea, is used as a test site. Due to different tidal ranges and phase at the ends of the channel, tidal currents of up to 8 m/s are generated in places in response to 2.5 m head drop [4], providing a substantial energy resource for turbine deployments [5,6]. Concerning sea bed morphology, a sandbank , located eastwards in Inner Sound Channel is of particular interest (Fig.1).Hydrodynamic boundary conditions established from a large scale flow model produced appropriate boundaries for nested areas favoured for tidal energy extraction (blue area marked in Fig. 1). Hydrodynamics of the model were validated against measured flows at 3 locations within the model domain (Fig. 2). Sensitivity tests were carried out on tuneable model parameters allowing confidence into investigating impacts of tidal energy converters on sea bed morphology.

Numerical Modelling and Results

In terms of flow modelling a full calibration analysis has been conducted so that an appropriate combination of Delft3D flow parameters could be applied in the area of interest. Hydrodynamic conditions of a large scale model (Fig. 1-domain (a)), covering the whole area of PF, were modelled and compared against ADCP measurements at 3 sites (Fig. 2, 3). Hydrodynamics of the large scale model provided appropriate boundary conditions for the nested, high resolution model (Figure 1 –domain (b)), which covers the areas favoured for tidal energy exploitation.

A good agreement is found between the modelled and measured values of current velocities at 3 ADCP sites. Observed deviations from ADCP records may be attributed to wave–current interactions. Baroclinic effects and stratification effects which may disturb the logarithmic vertical velocity profile were not taken into account in the present study. It should be noted that overall model output seems to be significantly sensitive to bed friction where a constant Chezy value of 50 $m^{(1/2)}$/sec is eventually selected.

Even though the sea bed in PF is mainly rocky, vast sand deposits are abundant in some areas. The sandbank (Fig. 1) is a large sand/gravel deposit located in this area. Into that sandy area highly mobile gravel form large sandy ripples, superimposed on small sand waves. To investigate the naturally occurring sediment dynamics in this area, a nested morphodynamic model, covering the Inner Sound Channel, was set up. The complex patterns of sediment distribution were encapsulated by considering varying sediment grain size and mobile seabed thickness. Sand coverage within the selected computational grid was produced via data interrogation accessed by Marine Scotland video trawls, BGS particle size processed data and mapped Geological conditions available by Meygen EIA Quality Mark Report [7]. Preliminary investigation of existing morphodynamics of the sandbank area during a full spring-neap tidal cycle shows that it is extremely dynamic. During the flow and ebb phases of the tidal cycle, transient eddies are apparent between the tip of the island of Stroma (Fig.1) and over the sandbank, indicating a possible connection between those transient tidal patterns and the formation and maintenance mechanisms of the offshore sandbank. At spring flood phase where velocities reach their maximum (up to 2.8 m/s), strong currents occur generally offshore of the southern flank of the sandbank. Currents flow towards the E-NE, being clearly affected by the presence of the Island of Stroma. At the same time, mean total sediment transport rates demonstrate increasing gradients towards the southern flank of the sandbank area.

Conclusions

Preliminary investigations indicate that sea bed morphology of sandy areas in PF is sensitive to hydrodynamics. Locations favoured for tidal energy extraction lie in proximity to highly sensitive sand/gravel deposits. As a result, it is important to investigate the impacts of tidal energy extraction on the hydrodynamics and the morphodynamics of this area. Numerical modelling study is still underway to investigate the linkage between the complex current patterns and the existing sediment transport regime. Following that, the models will be used to investigate the impacts of tidal current turbines on sea bed sediment dynamics.

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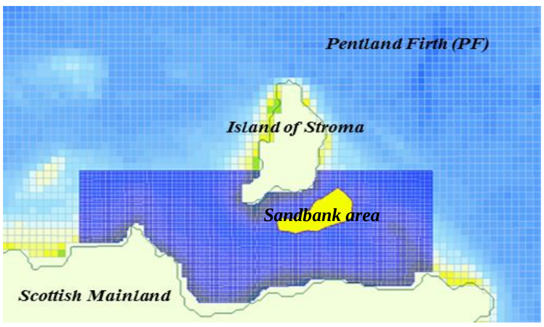

Figure 1: Sea bottom bathymetry inside PF

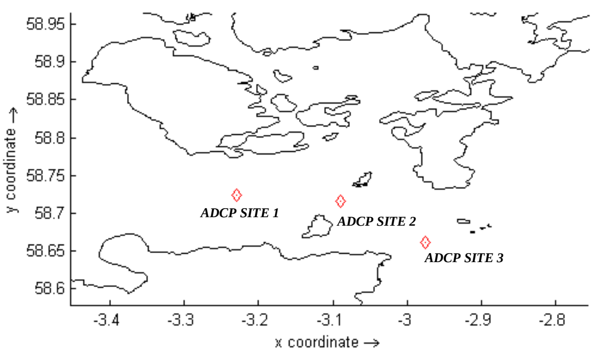

Figure 2: Location of ADCP record sites inside PF

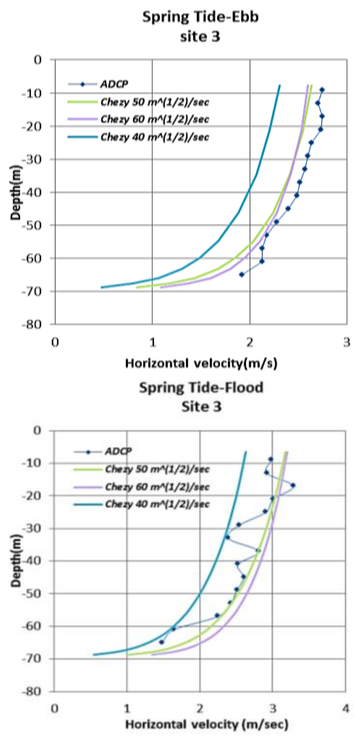

Figure 3: Calibration of flow model inside PF (Site 3)