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Changes to Eddy Propogation due to Tidal Array at Ramsey Sound

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ABSTRACT

This paper details a depth averaged finite element model of the Pembrokeshire coast. The influence of a 10MW tidal array at St David's Head is modelled as an extra sink in the momentum equations solved by the hydrodynamic software Telemac. Initial results show that, at St David's Head during a peak spring flood (2.74m/s), the wake of the array extends ~4km. Ramsey Sound is very turbulent environment producing large eddies. The changes to the hydrodynamics, by the array, directly influence the creation and propagation of these eddies. Initial investigations suggest the influence of these eddies propagations may extend as far 35km away.

INTRODUCTION

Recently, environmental impacts have been cited as reasons for a number of offshore wind farms no longer being developed [1]. As the focus on tidal energy technology increases, the need for determining their environmental impact is growing. To date, only single device tidal turbines have been installed to demonstrate the application of the technology. In absence of array scale developments, the far field effects from the interaction between the array and the physical environment are still subject to speculation.

A number of sites around the UK are being considered for development, one of which is Ramsey Sound, where flows are accelerated in a channel between Ramsey Island and the mainland. In 2011, Tidal Energy ltd (TEL) was given consent to test a prototype of their Delta Stream device in Ramsey Sound. Following successful testing, TEL is looking to develop a 10MW demonstration array just north of the Sound at St David's Head.

The aim of this research is to investigate how a 10 MW tidal array, situated at St David's Head, influences the local hydrodynamics and to determine the spatial extent around Ramsey Sound.

METHODOLOGY

A 2D depth-averaged finite element model of the Pembrokeshire coast has been computed on an unstructured mesh using the hydrodynamic software Telemac (v6p2). The mesh has a resolution of 3.6km around the boundary, focusing down to ~35m between Ramsey Island and the mainland, as seen in Figure 1. The hydrodynamics are forced using 13 tidal constituents from the Topex Poseidon database. The 1s (~30m) Astrium bathymetry is mapped onto the mesh. The model uses a k-ε turbulence model. The model time step is 10s, with results outputted every 15 minutes.

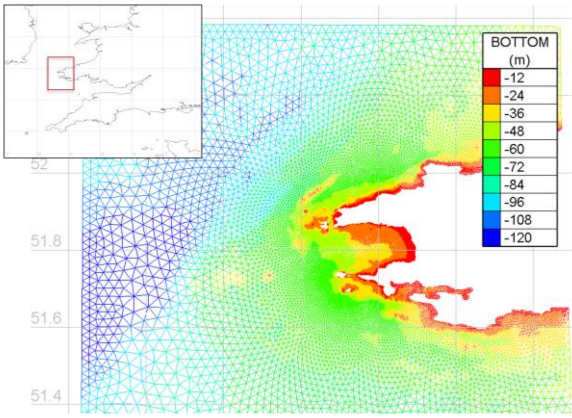

Figure 1 Model domain

The methodology used to represent a tidal array is the same as presented by Plew & Stevens [2]. Telemac solves as 2D flow using the Saint-Venant equations. The effect of a tidal array is introduced into the model as an extra sink in the momentum equations. This change in momentum is modelled as a drag force caused by the supporting structure and a thrust force produced by the rotor due to energy extraction. As the size of a turbine is smaller than the resolution of the mesh, the force is applied over an area to represent the array and not individual turbines.

There are a number of methods for implementing tidal arrays, but the method employed for this study provides a number of advantages. The first is the reduction of flow velocities due to the back effect of the array is taken into account. The kinetic flux method allows for potential power predictions but has been shown to be unsuitable [3] due to the lack of this phenomenon. The second advantage is that the drag is dependent on the flow conditions. Tidal turbines operate with a minimum cut-in speed and a rated velocity, meaning the thrust of the rotor changes with the velocity. Whilst studies have implemented a constant drag term in the momentum equation [4], this does not accurately reflect that operation of the turbine.

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The turbines, used for this study, are based on the published figures of the TEL Delta Stream device [3]. Each device consists of three 400kW rotors with a diameter of 18m. Each rotor reaches rated power at a velocity of 2.25m/s. A 10MW array contains 27 rotors. The hub height is 14m. It has been assumed the diameter of the support structure is 2m and the rotor has a cut-in speed of 0.8m/s.

To encompass both peak spring and peak neap conditions, a 30 day run, without the array, has been calculated to provide a base case to compare against the effects of the array. The effect of the array is calculated by subtracting the magnitude of velocity at each node of the mesh, of the turbine run, from the magnitude of the velocity in the base case. This is done for each time step, producing a temporal-spatially varying difference between the two models. A resulting positive value indicates an increase in speed and a negative value a decrease.

MODEL VALIDATION

Validation data has been obtained from the British Oceanographic Data Centre for currents and surface elevation [4]. Free surface comparison is taken at Milford Haven and Fishguard and shows almost perfect correlation. Data for validating tidal currents is scarce. At present, a 30 day ADCP record (starting 17th March 2000) has been used and, as seen in Figure 2, shows good correlation. However, its location is to the North West near the boundary of the mesh. More data is required near to the Sound to allow for a more robust validation.

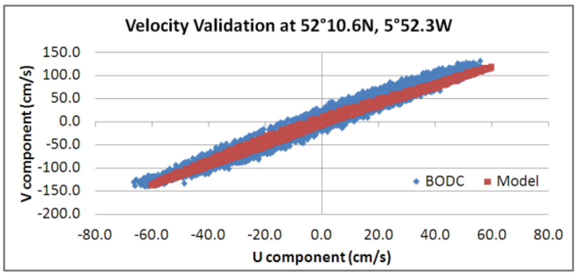

Figure 2 Validation of tidal currents

OBSERVATIONS

Ramsey Sound can be characterised as a complex environment. There is a strong disparity between the strength of the flood and the ebb tides, with the flood producing faster currents through the Sound. Line transects using an ADCP were undertaken within Ramsey Sound, on behalf of the Low Carbon Research Institute Marine Consortium. Results of the survey are published in [5]. Measurements showed velocities can reach 3.5m/s on the peak flood and ~1.8m/s on the peak ebb. In comparison, results taken from the model, show the peak spring velocity is 3.6m/s and 1.6m/s for the peak ebb. This suggests the model is reproducing valid flow speeds in the Sound.

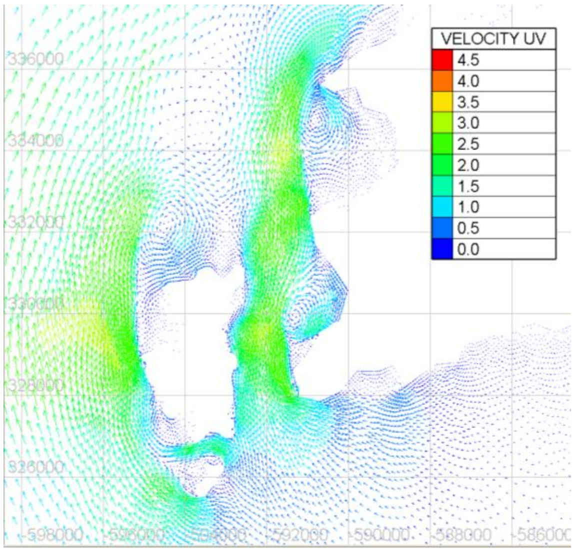

Figure 3 Eddy shedding off Ramsey Island

Ramsey Sound is a very turbulent environment due to its complex bathymetry. As a result there are many sources of disturbance. However, the biggest source of disturbance is Ramsey Island itself, where the flow of water through the Sound rejoins the main flow around the west of the island. Robinson [6] describes *"a discontinuity in velocity can occur when two separate streams of water from different bays, having different stagnation pressure or total head, meet at a sharp headland. The discontinuity of velocity is a vortex line that will gradually diffuse into the surrounding water"*. It can be seen, in Figure 3, that the model produces large eddy structures which form off Ramsey Island on the flood cycle, propagating northwards along the coastline.

When the tidal array is introduced to the model, initial results show the shadow effect of the array is more pronounced on the ebb cycle due to the eddy propagation. Figure 4 shows the shadow effect of the array during a spring ebb cycle. It can be seen that the flow returns to upstream velocities within 4km downstream of the array.

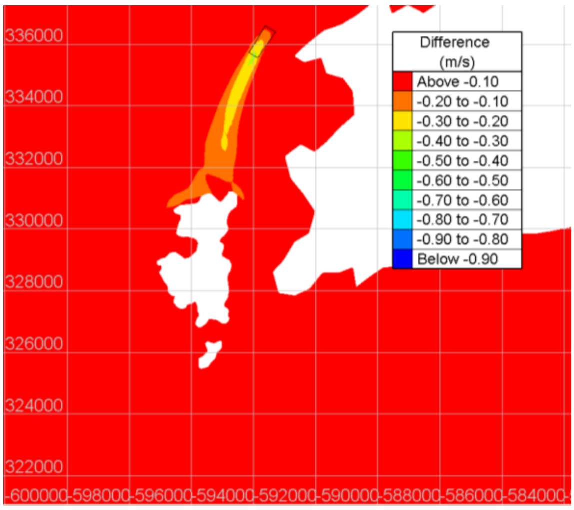

Figure 4 Reduction in flow speed caused by array

Subject to further validation, the velocities predicted by the model show, during a peak spring, can reach 2.74m/s at St David's Head. The results show the simulated array causes a reduction in velocity of, approximately 19%, directly in its wake. Black & Veatch [7] defines a 'Significant Impact Factor' (SIF) *"a percentage of the total resource at a site that could be extracted without significant economic or environmental impact"*, suggesting a value of 20%. The above results, therefore, suggest that the zone of influence is quite small and acceptable. However, further investigation would suggest otherwise.

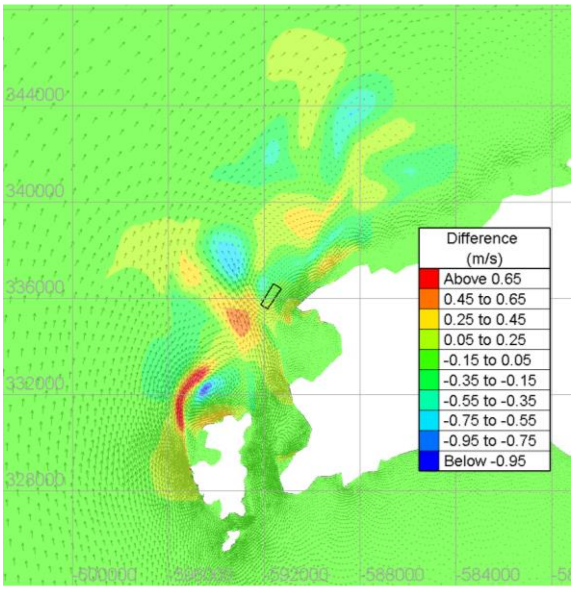

Figure 5 Changes in eddy propagation

As shown in Figure 4, the wake of the array, during an ebb cycle, reduces flow at the north of Ramsey Island. This area is a source of eddy generation. Changes to the hydrodynamics at this location influences how the eddies form and then propagate. It can be seen in Figure 5 that changes to the propagation of eddies can have far reaching impacts. Initial investigations suggest the influence of these eddies propagations may extend as far 35km away.

CONCLUSIONS

In the case study presented, the 10MW tidal array causes a maximum reduction, in velocities, of ~19%. The flow returns to upstream velocities within 4km downstream of the array. However, due to the proximity of the array the resulting wake effect directly influences the northern tip of Ramsey Island, an area of eddy formation. The resulting impact is large scale variation in the propagation of eddies, which may lead to far field effects greater than the wake of the array.

Whilst further validation of the model is needed, the results do provide an important insight. Investigations of tidal arrays are site specific and no generalised value of impact can be drawn. If a tidal array was sited such that it does not influence areas of vorticity generation, then the impacts would be greatly reduced. However, the sites of interest around the UK are typically in turbulent environments. The results show the need for high resolution modelling, at an appropriate scale, to be able to resolve the complex features of the environment.

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