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Tidal resource extraction in the Pentland Firth, UK: Potential impacts on flow regime and sediment transport in the Inner Sound of Stroma

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ABSTRACT

Large-scale extraction of power from tidal streams within the Pentland Firth is expected to be underway in the near future. The Inner Sound of Stroma in particular has attracted significant commercial interest. To understand potential environmental impacts of the installation of a tidal turbine array a case study based upon the Inner Sound is considered. A numerical computational fluid dynamics model, Fluidity, is used to conduct a series of depth-averaged simulations to investigate velocity and bed shear stress changes due to the presence of idealised tidal turbine arrays. The number of turbines is increased from zero to 400. It is found that arrays in excess of 85 turbines have the potential to affect bed shear stress distributions in such a way that the most favourable sites for sediment accumulation migrate from the edges of the Inner Sound towards its centre. Deposits of fine gravel and coarse sand are indicated to occur within arrays of greater than 240 turbines with removal of existing deposits in the shallower channel margins also possible. The effects of the turbine array may be seen several kilometres from the site which has implications not only on sediment accumulation, but also on the benthic fauna.

1. Introduction

Electricity generation from turbines driven by tidal currents present an attractive form of renewable energy, which is highly reliable and abundant in many coastal regions [8,13]. The UK is known to boast a significant proportion of Europe's extractable tidal resource, a large part of which is found in the Pentland Firth [8,45]. The Pentland Firth, shown in Fig. 1, lies at the northern tip of Scotland separating the Orkney Islands from the mainland to the south. This region is well known for the high speed of its tidal currents [14], and has consequently attracted significant attention as a possible site for the placement of tidal stream generators [45]. Promising regions for development are the Inner Sound, Outer Sound and South Ronaldsay Channel, shown in Figs. 1 and 2. Tidal currents within this region are influenced by local bathymetry and coastline, which ultimately determines their speed and direction [45].

The tidal regime in this area is dominated by the M2 component and thus involves a semi-diurnal exchange of water between the North Sea and Atlantic Ocean [45]. Tidal current velocities are at their greatest within the Outer Sound, with a mean spring velocity of just under 3 ms^{-1} and current speeds exceeding 1 ms^{-1} for 80% of each tidal cycle [45]. The Inner Sound and South Ronaldsay Channel also exhibit a useful tidal resource [8,13]. Commercial exploitation of this resource is expected to begin shortly with the planned placement of a demonstration array of 1 MW rated tidal turbines in the Inner Sound by MeyGen Ltd., based upon plans published in 2011 [44]. This would mark the beginning of a staged development process, which may ultimately see the operation of a 398 MW turbine array within the Inner Sound in the coming decades [44].

Previous studies of tides in the Pentland Firth suggest that it features significant tidal asymmetry, with maximum current velocities during flood tide being up to 2 ms^{-1} higher than those during ebb tide [18,45]. The nature of this asymmetry within the Inner Sound is discussed in Ref. [17] which presents the results of two Acoustic Doppler Current Profiler (ADCP) surveys of the Inner Sound. During flood tide, currents tend to flow west-east, and are concentrated within a distinct 'core' about 1 km south of Stroma [17]. During ebb tide currents flow east-west, the 'core' appears to

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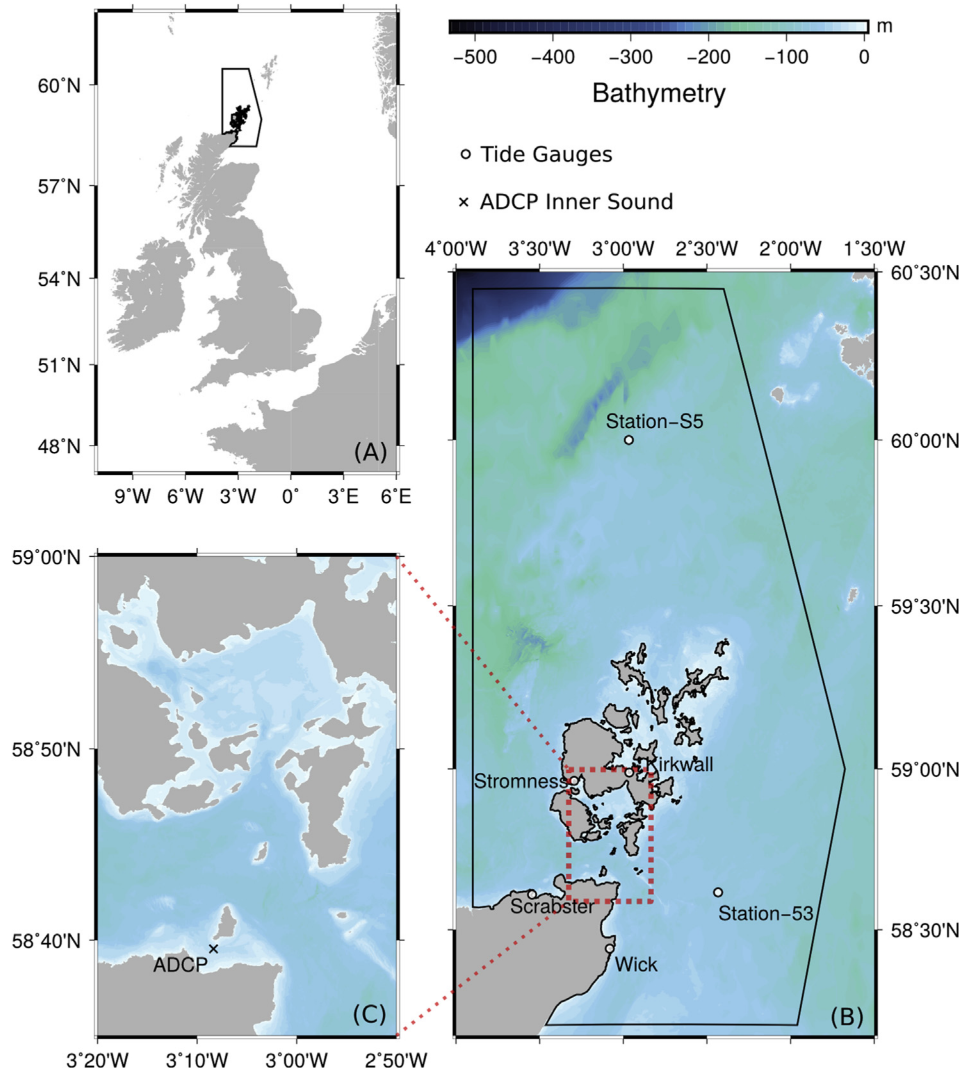

Fig. 1. Maps showing study location and simulated domain. A) Map of North-West Europe centred around the North Sea. B) Map of the simulation domain, the circular markers show the locations of tidal gauges. The thick outline (A and B) delineates the simulation domain and colour relief represents the resampled bathymetry used in this study. C) Map of the Pentland Firth and surrounding islands, the × marker show the location of the Acoustic Doppler Current Profiler (ADCP). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

be less distinct, and is located significantly further north. [17] also report the results of a sidescan sonar survey of the sea bed, which clearly indicates the presence of sedimentary structures concentrated in regions of low current velocities. Such results contrast with geological maps of the region, which suggest that the Pentland Firth is entirely composed of exposed bedrock [45]. Although the overall regime here is clearly erosional, very little is known about local scale variations in sediment transport, which serves to reinforce the need to understand these phenomena before the construction of tidal arrays gets underway. In order to begin to address such issues [17] construct a sediment transport model of the Inner Sound using the MIKE21 software package [47]. However Ref. [17], did not include the effects of tidal energy arrays in their study, but did show locations of sediment accumulation.

Many studies have indicated that the presence of a tidal turbine array within such a channel can have a significant influence on the flow regime and thus must be taken into account when attempting to assess the total extractable resource [2,37,38,46]. Of particular interest to this study is the potential ability of a turbine array to divert peak flows away from their natural path and thus alter patterns of erosion and deposition of sediment within the channel. Previous work, such as the 1D simulation carried out by Ref. [38] suggest that changes to the sediment transport regime may be particularly significant if the tidal currents are asymmetric, at least in estuarine environments. In such a tidal regime the net movement of sediment can occur in either the ebb or flood direction [38]. The effects of tidal energy converters on sediment transport may be seen several kilometres from the site of the energy converters. Effects are commonly categorised as near-field (<1 km), far-field (1–10 km) and regional (>10 km) [46]. Modelling studies on a sand-dominated system around Alderney, just off the coast of France, showed the potential effects on sediment movement could cover over 100 km^2 [37]. The effect is not limited to open marine systems, such as around Alderney, with estuarine environments also similarly affected [2]. Moreover Ref. [2], showed that the presence of turbines could also affect the distribution of faecal bacteria in the Severn Estuary, which is closely associated with sediment.

Movement of sediment into and out of areas can affect the local fauna [46] and is therefore an important component of any site