Sediment dynamics in the wake of a tidal current turbine

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Research outline

What will happen to the ocean floor after deployment of tidal turbines?

And in ten years time?

Will it have an impact on the habitat of marine plants and animals that dwell there?

The interaction between the wake that is produced downstream of tidal current turbines and the sediment on the seabed is the subject of present research.

PhD project of Lada Vybulkova
Wake Vorticity Field

Figure: Evolution of a wake vorticity field
Vorticity Transport Equation

Vorticity field \( \omega = \nabla \times \mathbf{v} \) is a solution of

\[
\frac{\partial \omega}{\partial t} + (\mathbf{v} \cdot \nabla)\omega - (\omega \cdot \nabla)\mathbf{v} = S_\omega + \nu \nabla^2 \omega
\]  

which is the curl of unsteady, incompressible *Navier-Stokes equations*\(^1\)

\[
\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} = -\nabla p + \nu \nabla^2 \mathbf{v}
\]

\[
\nabla \cdot \mathbf{v} = 0,
\]

the velocity field is a solution of

\[
\nabla^2 \mathbf{v} = -\nabla \times \omega
\]

and \( S_\omega \) is a source of vorticity.

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\(^1\)\( \nu \)... kinetic viscosity, \( p \)... 'pressure', \( \rho \)... density of the sea water
Vorticity Transport Model

**Figure:** Evolution of a wake vorticity field

- **Time = 84 s**
- **Time = 112 s**
- **Time = 140 s**
- **Time = 168 s**
- **Time = 224 s**

**Direction of the Flow**
Sediment uplift

Threshold condition for initiation of motion - Bed Shear Stress $\theta > \theta_{cm}$.

\[
\theta_{cm} = 0.14(d^*)^{0.64},
\]

\[
d^* = d \left( \left( \frac{\rho_s}{\rho} - 1 \right) \frac{g}{\nu^2} \right)^{1/3}
\]

is the dimensionless sediment size.\(^2\)

Amount of sediment coming into suspension $\sim$ erosion flux $\left(\text{kgs}^{-1}\text{m}^{-2}\right)$

\[
E = E_0 \left( \frac{\theta}{\theta_{cm}} - 1 \right)
\]

where erodibility $E_0$ is determined experimentally for the particular flow situation.

The ambiguity was avoided by definition of a relative quantity expressing the impact of a TCT on the seabed.

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\(^2\rho_s\ldots\text{sediment density}, g\ldots\text{gravity and sediment size } d\)
Relative Excess Erosion Flux (REEF)

\[ S_r = \sum_{i \in \text{grid}} \left( \frac{E_i}{E_{fs}} - 1 \right), \quad (8) \]

represents a relative increase in erosion flux caused by presence of a tidal turbine with respect to \( E_{fs} \), the erosion flux caused by the inflow only.

The REEF caused by a TCT is influenced by

Proximity to the seabed, flow conditions - inflow velocity, Tip Speed Ratio, parameters of the device - number of blades, rotor diameter, blade twist distribution, etc.
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Ground Effect

Figure: Slices through the wake velocity field, $|V| \left[ \text{m s}^{-1} \right]$

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**Ground Effect**

**Figure:** Slices through the wake velocity field, $|V|$ \([\text{ms}^{-1}]\)
Figure: REEF change with the proximity to the seabed
Figure: REEF change with the Tip Speed Ratio

Relative Excess Erosion Flux, TSR variation

- TSR = 5.39, $C_p = 0.117$
- TSR = 6.67, $C_p = 0.122$
Figure: REEF for various blade twist distributions

Table: Power coefficient of used twist distributions

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<tr>
<th>Twist</th>
<th>TW1</th>
<th>TW2</th>
<th>TW3</th>
<th>TW4</th>
<th>TW5</th>
<th>TW6</th>
<th>TW7</th>
<th>TW8</th>
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</thead>
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<td>$C_P$</td>
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<td>0.111</td>
<td>0.110</td>
<td>0.102</td>
<td>0.108</td>
<td>0.091</td>
<td>0.117</td>
<td>0.113</td>
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</table>
Conclusions and ongoing research

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The nature and scale of the change of sediment dynamics in relation to various factors is the subject of ongoing research at the University of Glasgow.

Present results indicate long-term cumulative effects on the ocean floor, caused by presence of a TCT over a period of decades.
Thank you.