Modeling of hydrodynamics and sediment transport around tidal stream turbines in ZhouShan water, China
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ABSTRACT
A 2D coupled numerical model based on TELEMAC is established to simulate the hydrodynamics and sediment transport around tidal stream turbines in Zhoushan water, China. The effects of an array with 18 turbines on hydrodynamics and sediment transport are studied. The results show that the deployment of turbines results in an increase of velocity at the channel between Hulu Island and deploying area, which further leads to the increase of Suspended-sediment concentration (SSC). It is also demonstrated that bed erosion behind the array is significantly reduced, and even turns to deposition within the range of 20D on the north side of the turbine array.

KEY WORDS: TELEMAC; Tidal stream energy; Turbine array; Hydrodynamics; Sediment transport.

INTRODUCTION
As a green, renewable and predictable marine energy, the rational development and utilization of tidal stream energy has been an important means to alleviate the energy crisis and reduce environment pollution. The coastal areas of China are abundant in tidal energy resource, estimated at 13.95GW, half of which is distributed in the water of Zhejiang province (Wang et al., 2011). The first tidal stream energy demonstration project is located in Zhoushan water, Zhejiang. The maximum tidal stream velocity there is above 1.7m/s and the water depth about 20m-60m (Wang et al., 2011). Although tidal stream generation has attracted much interests, the scientific basis on the effect of tidal stream turbines on the environment is still lacking (Frid et al., 2012). The environmental monitoring is an important way to study the influence of tidal stream turbines on hydrodynamics and sediment transport, but it needs a couple of years to get the feedback. Therefore, numerical modeling becomes an effective alternative for this purpose.

To date, many research works have been done on the impacts of tidal stream turbines on the surrounding hydrodynamics. Neill et al. (2009) investigated the influence of a tidal turbine farm in the Severn estuary (UK) by using a 1D numerical model. It is proposed that the energy extraction is analogous to increasing the bottom friction in the region of extraction, and then altering the hydrodynamic of the surrounding area. Then, they developed a 3D model to study the effect of turbines on the hydrodynamics in the Alderney Race (Neill et al., 2012). With a 2D numerical model, Plew and Stevens (2013) assessed the influence of a tidal turbine array on the hydrodynamic in the Tory Channel, New Zealand. Velocity-dependent turbine thrust and the structural drag were introduced as a stress term in the momentum equations to represent the turbines, which is more realistic than conventional parameterized methods. Considering the effects of waves, Hashemi et al. (2015) developed a hydrodynamic model based on TELEMAC-2D and investigated the variation of tidal energy caused by waves. It is demonstrated that tidal energy output from a turbine array would be reduced by up to 15% and 20%, for mean waves and extreme waves in winter, respectively. In terms of experiments, Zhang et al. (2020) conducted a series of flume tests to study the wake flow of a pile-supported horizontal axis tidal stream turbine. Specific to the Zhoushan water, some researches about tidal stream energy assessment and the optimization of the turbine array have been reported (Gao et al., 2015; Wang et al., 2017; Zhang et al., 2020).

Sediment dynamics is also required to better evaluate the environmental response caused by tidal turbines. Large-scale development of tidal stream turbines will have a significant impact on regional sediment transport and bed evolution, especially in the areas of strong tidal symmetry (Neill et al., 2009). Further simulations found that the tidal turbine array would interfere with the natural morphodynamics of the headland system, which played an important role in coastal protection (Neill et al., 2012). Fairley et al. (2015) established a 3D coupled hydrodynamics and sediment dynamics model based on MIKE3, and investigated the effects of tidal turbine arrays on sediment transport and bed evolution in the Pentland Firth, Scotland. The relationship between the influence of an individual tidal turbine array and cumulative impacts of multiple arrays was also illustrated. A 2D numerical model was used to study the effects of turbines on sediment transport in Alderney Race, France (Thiébot et al., 2015). It is demonstrated that tidal energy extraction would alter the deposition area of the particles transiting through the tidal turbine array and the location of arrays would affect the sediment mass balance between different sea areas. To accurately predict the suspension strength and SSC in the wake area of turbines, Li et al. (2020) proposed two approaches to modify the calculations of bed shear stress and turbulent mixing in the presence of turbines. A series of experiments were conducted to verify the model, and the impacts of turbines on the