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Dynamics of sediment disturbance by periodic artificial discharges from the world's largest tidal power plant

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ABSTRACT

To investigate the dynamics of sediment disturbance near the world's largest Sihwa tidal power plant (TPP), two mooring observations have been conducted. The mooring results show that current velocity and suspended sediment concentration (SSC) were significantly disturbed over various time scales. On the short-term (flood–ebb) time scale, resuspension of bottom sediment is mainly controlled by the strong jet-flow (>2 m s^{-1}) and resulting anticlockwise rotating vortex associated with the artificial discharge. During ebb phase, the strong flow resulted in suspension of high-concentration near-bed sediment and seaward transport of the suspended sediment. After turning to flood phase, the vortex produced secondary SSC peaks, transporting the suspended sediment toward the Sihwa TPP. The most active suspension of bed sediment predominantly occurred during 1–2 h immediately after the start of artificial discharge. For the fortnightly (spring–neap) time scale, SSC during spring tide was approximately 2–5 times higher than that during neap tide. During the combined period of ebb and spring tides, in particular, the periodic artificial discharge can enhance the responses of SSC in the vicinity of Sihwa TPP.

1. Introduction

As a future source of marine renewable and sustainable energy, tidal energy has attracted considerable interest in coastal regions (Rourke et al., 2010a; Tolón-Becerra et al., 2011). Numerous tidal power plants (TPPs) have been constructed, of which the plant at La Rance is a renowned example, and potential candidate sites are still being proposed and evaluated to meet the continued increase in society's electricity demands (Charlier and Finkl, 2009; Rourke et al., 2010a). Energy exploitation by a TPP is an infinite energy source which can produce electricity based on the impounded surface area and the square of the water level difference inside and outside of the seawall (Rourke et al., 2010b; Angeloudis and Falconer, 2017, in press). Despite the economic benefits, it has been reported that anthropogenic activities associated with the construction and operation of a TPP could create serious problems in the associated hydrodynamics and sedimentary processes (Kirby, 2010; Xia et al., 2010; Neill et al., 2012; Ahmadian et al., 2014; Ramos et al., 2014; Zhou et al., 2014).

Lake Sihwa, an artificial lake formed by a seawall, is located in the southern part of Gyeonggi Bay, on the west coast of South Korea (Fig. 1). After the construction of the seawall, leading to the restriction of free exchange between freshwater discharge and seawater, sedimentation and water pollution worsened with continuous point and non-point contaminant inputs from agricultural and industrial wastes (Han and Park, 1999; Li et al., 2004; Rostkowski et al., 2006). Serious pollution by heavy metals and toxic organic contamination of bed sediment has been reported (Khim et al., 1999; Yoo et al., 2008; Oh et al., 2010; Choi et al., 2011; Ra et al., 2011). To solve such problems, desalination of Lake Sihwa was abandoned in December 2000. Instead, the government decided to construct the Sihwa TPP in the middle of the seawall for tidal power generation and water quality improvement. Lee et al. (2014) mentioned that the water quality can be locally improved by the increase of seawater circulation associated with operation of TPP. Because the Sihwa area has a peak spring tidal range of about 8 m, it has been considered for many years an excellent site for electricity generation. At this time, it is the largest TPP in the world among the operating tidal power stations in terms of power capacity. The total power output capacity is about 254 MW (Bae et al., 2010). Power is generated only during flood phase, when the tidal current flows from the sea into the enclosed basin of Lake Sihwa.

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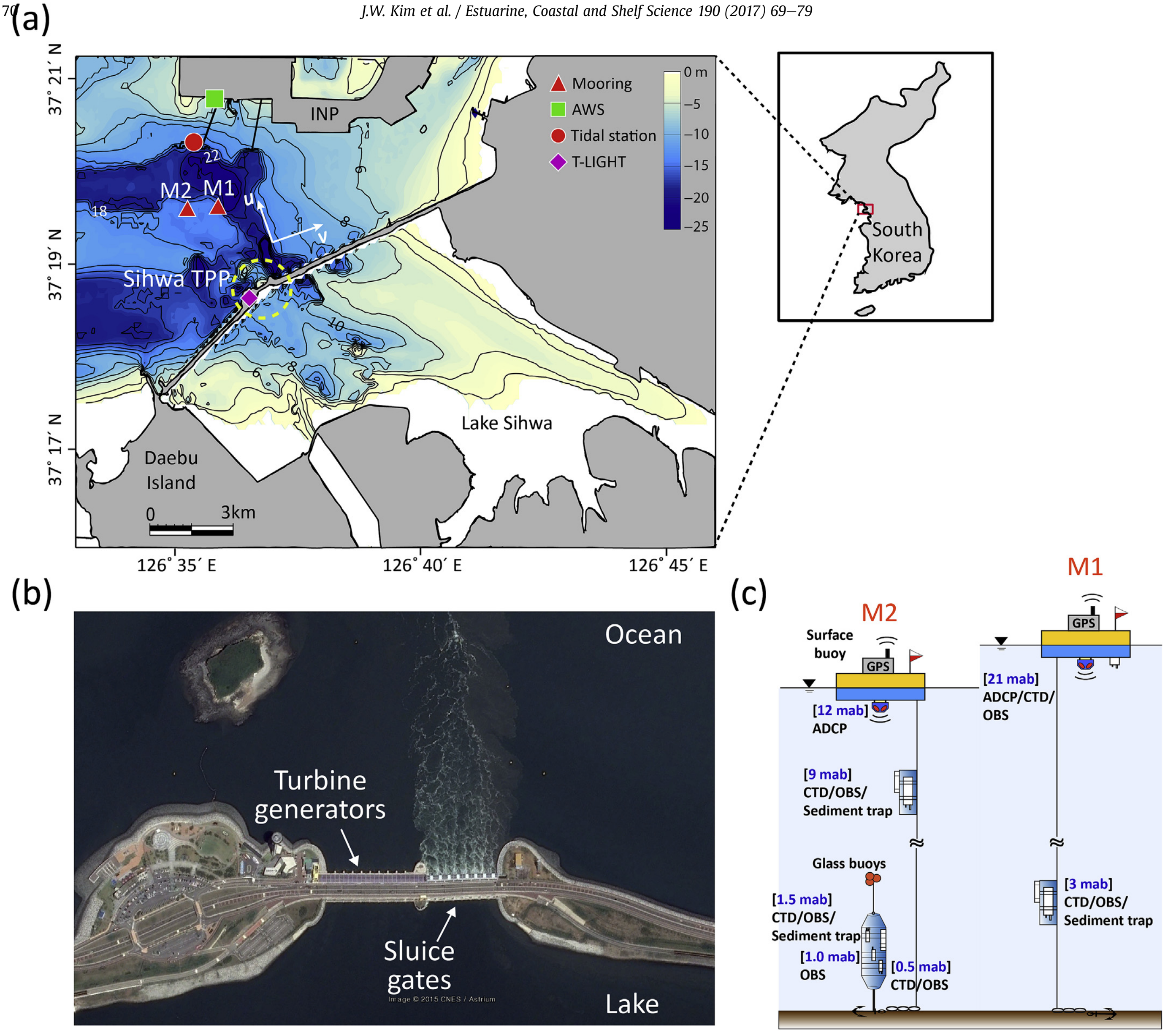

Fig. 1. (a) Map showing Lake Sihwa and the adjacent region. Hydrographic data was collected at two mooring sites (red triangles, M1 and M2), atmospheric data was collected at the AWS (green square), tide data was collected at the Songdo tidal station (red circle) by the Korea Hydrographic and Oceanographic Agency, and discharge data was collected at the T-LIGHT station (purple diamond). ADCP velocities were rotated +9.21° as shown, to represent along (u) and across (v) channel components. The along-channel velocity is parallel with the axis of the artificial discharge. INP denotes Incheon New Port. (b) Strong jet-flow of artificial discharge captured by satellite (source: Google Earth), and (c) conceptual design for moorings M1 and M2 (not to scale). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

During ebb phase, the outgoing water passes through the sluice gate without generating any power. Such a repetition of inflow (flood) and outflow (artificial ebb discharge) caused salient changes in the hydrodynamics and sedimentary processes (Susaya et al., 2011; Kang et al., 2013). In particular, the strong artificial discharge could endanger ship traffic moving along the navigation channel in front of the Sihwa TPP.

To date, most studies for Sihwa TPP have primarily dealt with the biochemical processes associated with metals and toxic organic contamination and with ecological disturbance of benthic organisms within Lake Sihwa (e.g., Baek et al., 2011; Ra et al., 2011). A few studies, nonetheless, have attempted to investigate hydrodynamics and suspended sediment transport (e.g., Bae et al., 2010). In order to understand disturbed sediment transport processes during its operation, two in-situ moorings were installed in front of the Sihwa TPP. The primary goal of this study is to examine the effects of

Table 1
Setup details and SSC responses of the two mooring systems.

	M1	M2
ADCP		
Bin size (m)	0.50	0.25
Ping interval (sec)	0.2	1
Burst interval (min)	10	30
Deployment depth (mab)	21	12
Blanking distance (m)	0.88	0.50
CTD and OBS		
Sampling rate (Hz)	4	4
Sampling interval (min)	2	2
Deployment depths (mab)	2 levels (21 and 3)	4 levels (9, 1.5, 1.0 and 0.5)
Mean SSC_{ADCP} (mg l^{-1})		
Spring tides	27.93	25.77
Neap tides	5.73	13.46