Optimizing Hydropower Facility Operations Via Acoustic Sediment Monitoring

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Extended Abstract

Hydroacoustic monitoring of sediment movement in rivers with hydrophones and geophones has become increasingly popular among agencies and research institutions in recent years, as it provides continuous and unattended observations of sediment movement in a river (e.g., Gray et al., 2010; Hilldale et al., 2014; Rickenmann, 2017). This paper presents the application of a hydroacoustic sediment monitoring system for continuously tracking the relative amount and timing of sediment conveyed through hydropower facilities that builds on testing conducted at pipeline crossing and river systems. The developed hydroacoustic sediment monitoring system allows evaluating when sediment is mobile at the intakes of hydropower facilities and provides their operators with valuable, real-time information on sediment movement. This information can be used to optimize hydropower generation, especially the timing and duration of drawdowns for sediment flushing and flood regulation. The paper first presents the main components that comprise the hydroacoustic sediment monitoring system and then results, which were collected during its deployment at a hydropower facility and demonstrate its capability to monitor sediment movement at the facility intake.

The basis of the developed hydroacoustic sediment monitoring system is a hydrophone sensor that measures the sound generated by the sediment moving at the intake (Figure 1a and b). The hydrophone sensor is mounted on the end of a steel pipe (Figure 1b), which is placed vertically at the intake of a hydropower facility, such that the hydrophone remains submerged during the expected flows at the intake. The hydrophone captures the sound signals that are produced by interaction of moving sediment particles with the bed during a 1-minute interval every 5 minutes. These signals are amplified (Figure 1c) and then recorded on a computer (Figure 1d) as sound files, which are then processed using software developed as part of this project. The processing involves a series of filters to remove noise introduced into the acoustic signal by ambient sources and the electronics. The filtered data are then used to derive the number of sediment particle impacts that have occurred per minute, as well as other descriptive statistics that index how much sediment is moving. This information is conveyed to the facility Program Logic Controller (PLC) using the MODBUS protocol enabling operators to monitor sediment mobility in real-time. The data are also stored remotely in the Aquarius Time-Series database of Northwest Hydraulic Consultants (NHC) and published using the Aquarius Web-portal to provide plant managers and NHC scientists the opportunity to conduct more detailed analysis including the identification of long-term trends in sediment movement patterns.

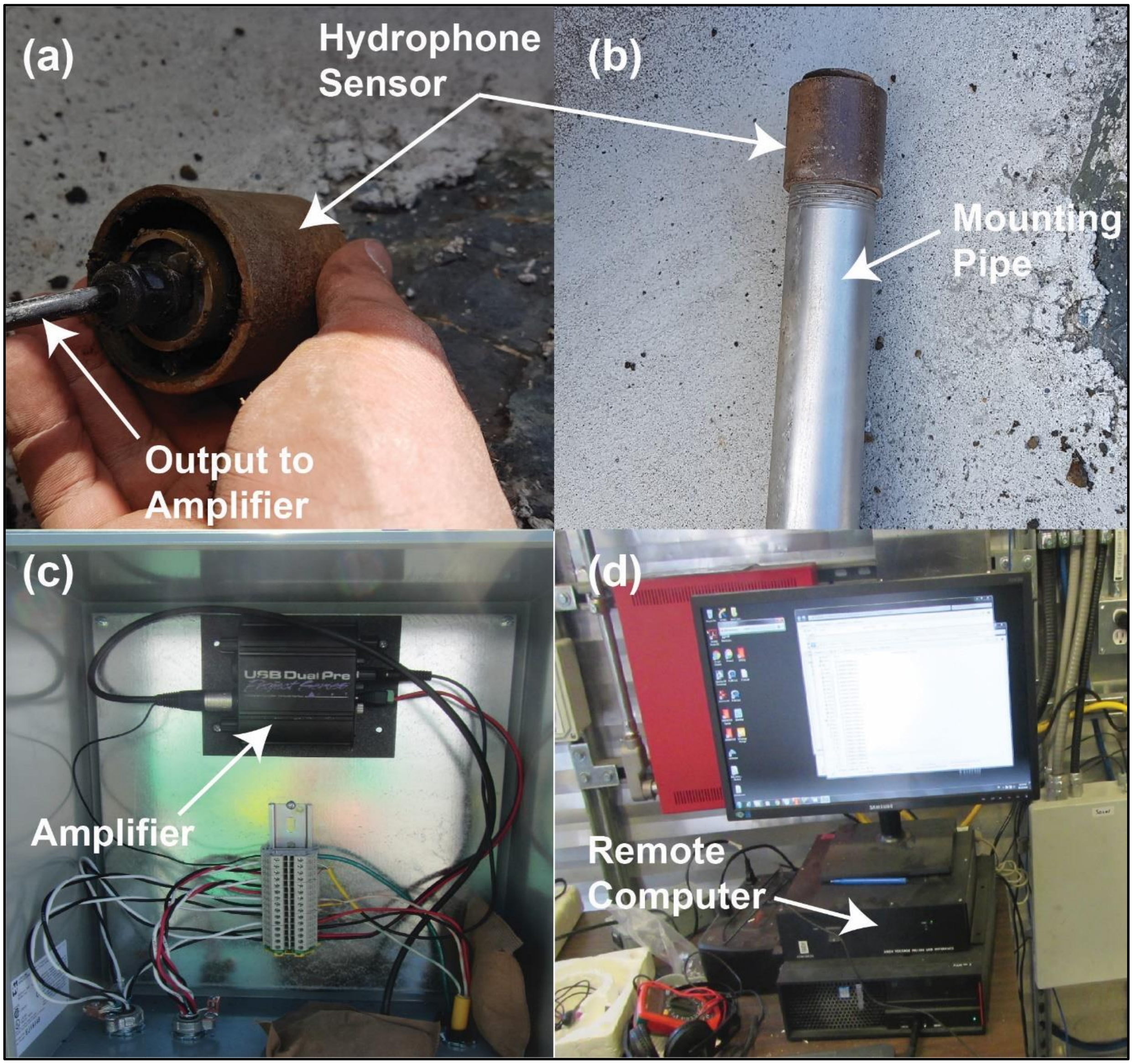

Figure 1. (a) Hydrophone sensor; (b) hydrophone sensor mounted on metal pipe; (c) remote computer for logging; (d) hydrophone signal amplifier

The performance of the sediment acoustic monitoring system was assessed at the Forrest Kerr and the Upper Lillooet hydroelectric facilities, which are located on the Iskut and Lillooet Rivers, respectively. The sediment acoustic monitoring system deployed at the Forrest Kerr facility is considered in this paper for demonstrating the capability of this system. The Forrest Kerr hydropower facility is located in Northwest British Columbia at the confluence of the Iskut River and the Forrest Kerr creek. The facility operates as a run-of-the-river plant and is capable of 195 MW of power generation diverting approximately 8,300 cubic feet per second (250 cubic meters per second). The facility features a sluiceway, which is used to convey incoming bedload to the reach downstream of the facility, thus preventing it from entering the turbine intakes (Figure 2). The hydrophone was deployed along the left bank, near the entrance of the sluiceway for detecting sediment moving in the sluiceway (Figure 2).

Figure 2. Aerial view of the Forrest Kerr hydropower facility and location of the hydrophone sensor (image from Bethany Duarte, HydroReview)

A hydrophone recording from the Forrest Kerr facility between August 27, 2018 and September 17, 2018 is shown in Figure 3 along with the water discharge measured at the plant intake over the same period. The results in Figure 3 show that the hydrophone is capable of detecting the commencement and cessation of sediment motion, which are characterized by a sudden increase and decrease in the detected number of particle impacts. Knowledge of the incipient and cessation of sediment motion further allows estimating the duration of sediment motion.

At the same time, the results in Figure 3 show that the deployed acoustic monitoring system may provide an estimate of the relative magnitude of the amount of sediment that is being transported. During the period between August 30th, 2018 and August 31st, 2018 more than 1.5 million particle impacts were recorded with up to 19,300 particle impacts recorded during a 1-minute recording interval. In the subsequent, smaller flood occurring between September 9th and 12th 2018, only up to 2,200 particle impact detections in a 1-minute interval were detected thus indicating lower mobilization of particles in comparison to the August 30th-31st event.

Synchronous monitoring of the flow discharge along with particle impact number, as in Figure 3, helps to identify the effects that facility operations have on the magnitude and timing of the sediment movement. An increase in the sluiceway discharge for sluicing sediment on August

27th, 2018 resulted in significant sediment mobilization captured by the hydrograph. The hydrophone results show that sediment during this event was predominantly mobilized as the sluiceway discharge was increased, suggesting that an ample supply of sediment had accumulated at the headpond prior to this sluicing event (e.g., Mao et al., 2014). The sluicing of sediment in this first sluicing event depleted its availability in the headpond, leading to smaller sediment mobilization during the larger flows between August 28th and 30th, where fewer particle impacts were detected by the hydrophone. Once the flow in the sluiceway was reduced between August 30th and 31st, 2018, a large sediment transporting event was detected by the hydrophone. This second sediment transporting event occurred during the falling limb of the hydrograph (Figure 3) and is indicative of counterclockwise bedload transport hysteresis due to the limited mobile sediment availability (e.g., Mao et al., 2014).

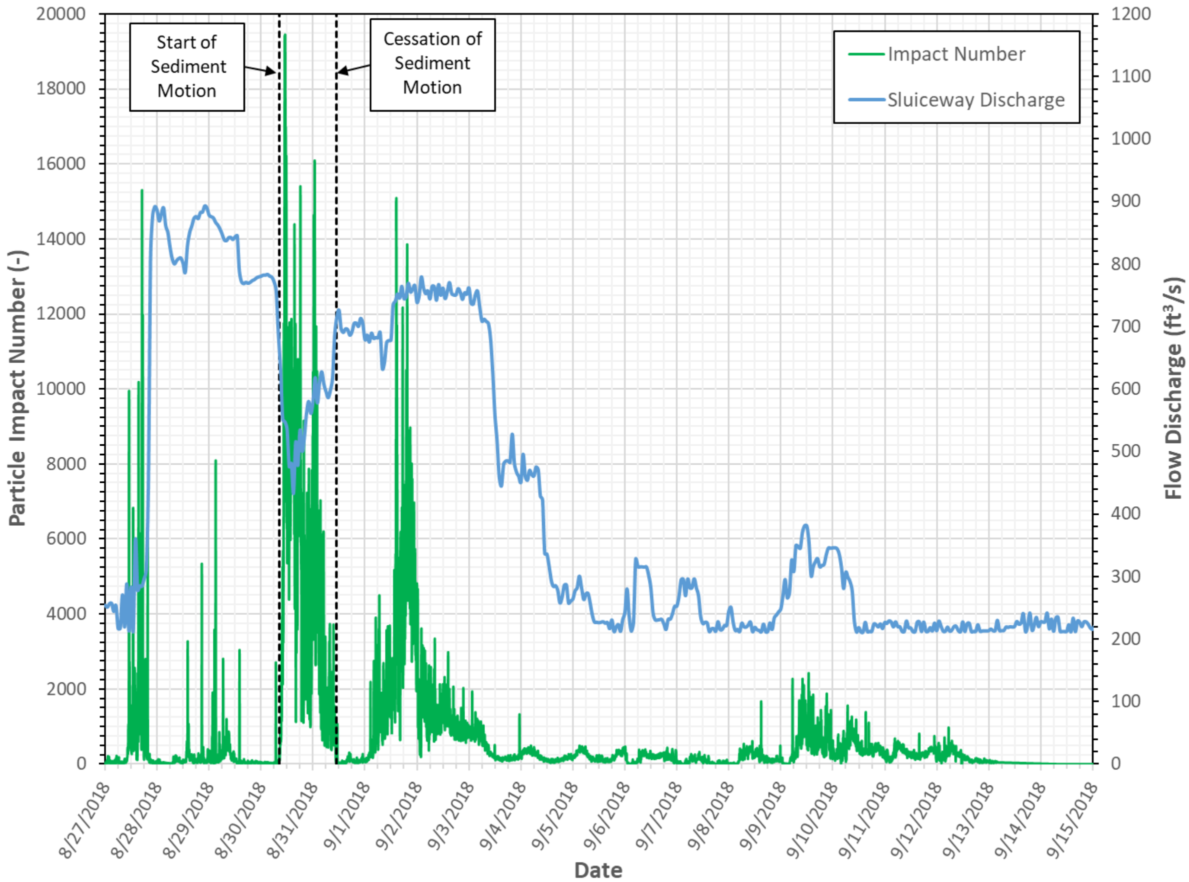

Figure 3. Number of particle impacts recorded by the hydrophone and corresponding discharge measured at the Forrest Kerr facility intake between 8/27/2018 and 9/15/2017

The data obtained with the acoustic sediment monitoring system since its deployment shows that the system is capable of monitoring the timing and relative magnitude of sediment movement at hydropower facilities on a continuous basis. The system can thus provide managers and operators of hydroelectric facilities with a reliable tool for optimizing their operation (see also Zimmermann et al., 2019 in these proceedings). The acoustic sediment monitoring system could also be deployed at other locations along a river and be used to assess when coarse sediment particles (e.g., gravel and cobbles) start to move and the relative intensity of their movement. Such information can help operators and scientists understand the conditions that lead to the incipient motion of sediment particles and provide useful information for studying the hysteresis in their movement. Along these lines, future work will aim to distinguish the different mobile sediment size fractions based on the acoustic frequency signatures of each fraction (Tsakiris et al., 2014).

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