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# Using Buried Accelerometers to Measure the Timing of Bed Movement, Scour, and Fill in Gravel-Bedded Rivers

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## ABSTRACT

The timing and depth of streambed disturbance and resulting scour and fill is difficult to measure, especially in large, gravel-bedded rivers. Most scour monitoring data have been limited to quantifying the total amount of scour over individual high-flow events or an entire flood season using conventional methods like scour chains. We present a novel method for measuring the timing of streambed scour and fill during a flood season using buried data-logging accelerometers. The accelerometers were deployed at the start of the flood season and programmed to record their three-dimensional orientation every 20 minutes. The accelerometers autonomously recorded the timing of the disturbance of the surrounding gravel matrix during high-flow events and, therefore, recorded the timing of scour and fill on the riverbed. We demonstrate the effectiveness of this method in recording streambed dynamics during the 2010–2011 flood season in the Cedar River, Washington.

## INTRODUCTION

Streambed scour is an important geomorphic process that affects sediment transport, channel form, and aquatic biota, but is difficult to measure in the field. Early attempts at measuring the spatial distribution of scour included the deployment and resurveying of scour chains, which mechanically record the maximum depth of streambed disturbance and the depth of subsequent fill (Emmett and Leopold, 1965). This design was later modified by adding sliding indicators that are exhumed as streambed disturbance depth increases (Klassen and Northcote, 1986). These methods have been widely implemented, but are not able to resolve the temporal history of streambed scour within a high-flow event when scour monitor recovery is impractical and potentially hazardous. The development of scour monitors capable of recording the temporal history of scour has been much more limited (Cascades Environmental Services, 1991; DeVries and others, 2001) and scour monitors that record the timing of bed restabilization have not been developed.

The objective of this study is to present a new method for determining the spatial and temporal distribution of streambed gravel disturbance during a high-flow event. Disturbance of streambed sediment near salmon-spawning habitat was evaluated in the Cedar River, Washington, using accelerometers that autonomously record their orientation, and therefore, disturbance of the surrounding gravel matrix during a period of several months encompassing an entire flood season. The resulting time series of disturbance provides valuable insights into the temporal and spatial distribution of scour of potential salmon redds during high-flow events and to a lesser extent patterns of fill.

## CEDAR RIVER

The Cedar River flows about 72 km from its headwaters in the Cascade Range into Lake Washington and has been regulated by a dam at the outlet of Chester Morse Lake since the early twentieth century (fig. 1). Flow regulation and floodplain alterations, including bank protection structures such as revetments, have contributed to channel narrowing, reduced number of side channels, and have limited channel migration and sediment supply. Flood hydrology is dictated by heavy and prolonged winter rain events with the largest flooding occurring when the basin is in the path of atmospheric rivers (relatively narrow bands of high-moisture air advected from the tropics). Several species of anadromous salmonids spawn and rear within the Cedar River including native Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and introduced sockeye salmon (*O. nerka*). In autumn, spawning salmonids construct depressions called redds where the female deposits her eggs and covers them with a clean layer of gravel following fertilization. During the development of salmonid embryos within river gravels, gravel movement such as scour and fill may adversely affect the survival of salmonid embryos and is thus a key constraint on salmonid population viability.

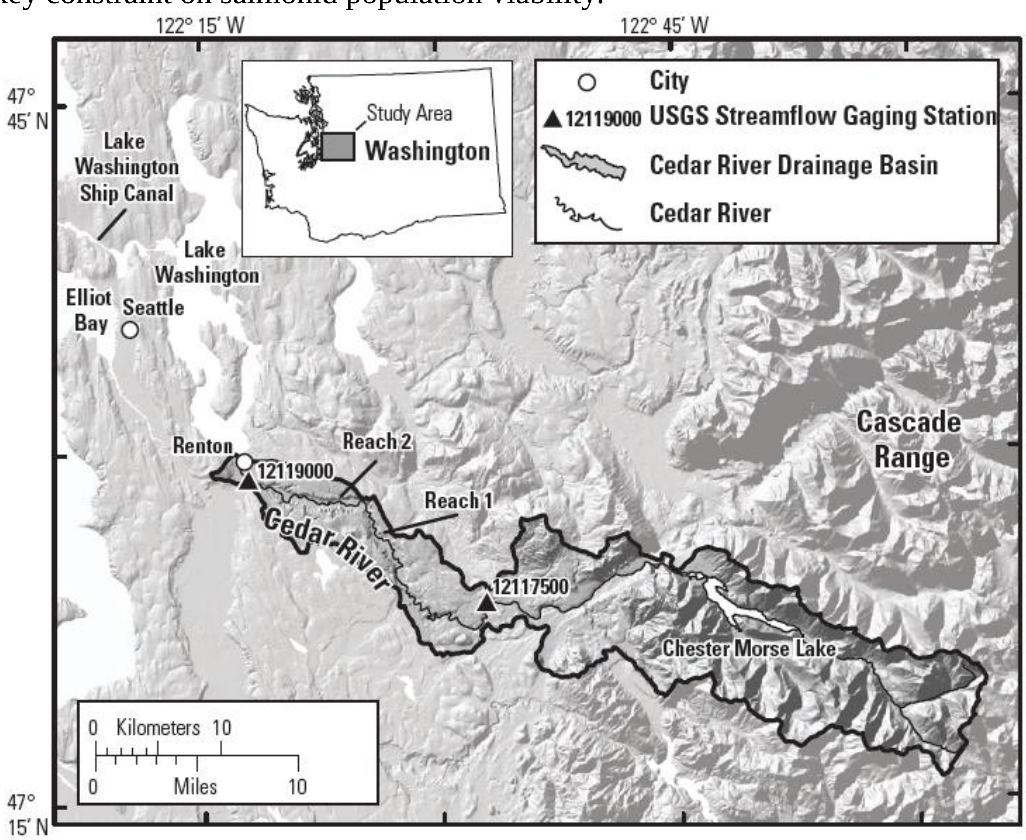


**Figure 1.** Location of study reaches within the Cedar River drainage basin, Washington. Hillshade image acquired from 1 arc-second U.S. Geological Survey topographic data.

## ACCELEROMETER SCOUR MONITORS

Accelerometer scour monitors (ASMs) offer a new approach to measure the temporal dynamics of streambed disturbance based on data-logging accelerometers buried in river gravels that builds upon the work of Cascades Environmental Services (1991) and DeVries and others (2001). Accelerometers electronically record their three-dimensional orientation relative to gravity, a change to which is interpreted as the disturbance of the surrounding gravel matrix. ASMs also provide a measure of the total depth of scour and fill similar to conventional scour monitors.

The ASMs were constructed with two Onset® HOBO Pendant® G accelerometers encased in 8-cm lengths of 4-cm diameter schedule 40 PVC tubing attached independently by braided steel wire to a 10-cm angle-steel anchor (fig. 2) (use of trade or brand names in this paper is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey). The PVC tubing was weighted so that each ASM had a density comparable to streambed sediment of approximately 2.6 g/cm$^3$. A pounding device similar to that used by Klassen and Northcote (1986) was used to create a hole within the streambed while minimizing disturbance of adjacent sediment. The burial depth of the accelerometers ranged from 7 to 63 cm and was determined from direct measurement of the anchor depth and the length of the braided cables attaching the accelerometers to the anchor. The elevation and coordinates of the streambed above each ASM was surveyed using a real-time kinematic global positioning system (RTK-GPS), which had a vertical and horizontal accuracy of approximately ±3 cm, comparable to the streambed grain roughness.

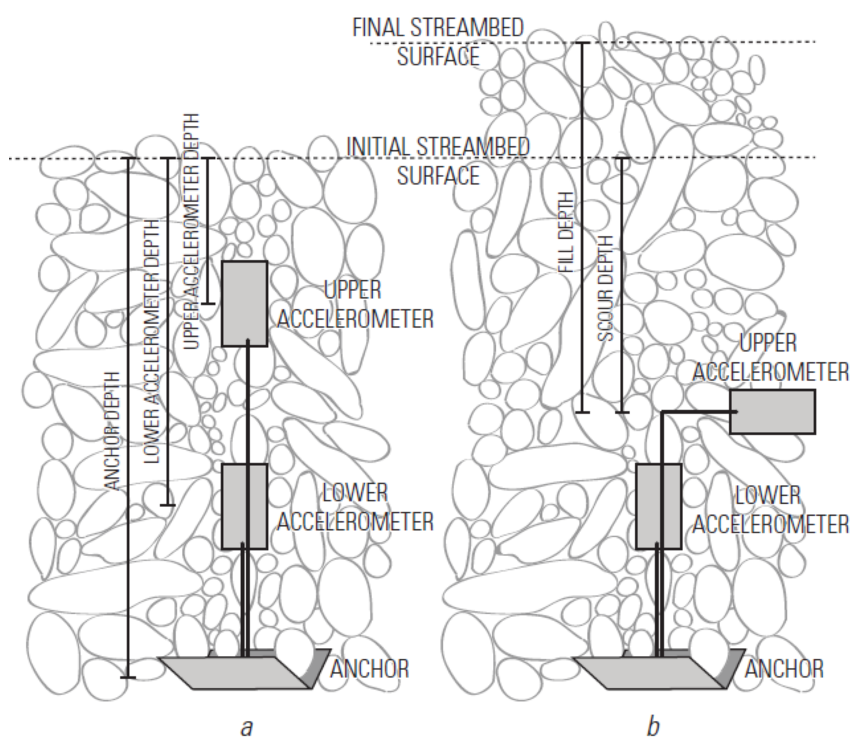


**Figure 2.** Schematic of accelerometer scour monitor (ASM) deployment with (*a*) initial deployment of two accelerometers deployed in series and (*b*) final orientation of ASM after flood season, enabling the measurement of net disturbance and fill.

ASMs were deployed at 26 locations in two reaches of the Cedar River (fig. 1) and were programmed to record tilt of three axes at 20-minute intervals beginning on October 1, 2010, which allowed continuous data logging throughout the entire 2010–2011 flood season (until June 2011). For this study, the ASMs were located so that the upper accelerometer (median depth 18 cm) was near the top depth of Chinook and sockeye salmon egg pockets and the lower accelerometer (median depth 45 cm) was near the bottom depth of Chinook and sockeye salmon egg pockets. Streambed elevation prior to ASM recovery was surveyed to determine net bed-elevation change. The elevation of each ASM was surveyed to determine maximum scour depth during the 2010–2011 flood season. Four conventional scour chains were deployed in proximity to a group of ASMs to verify the extent and depth of scour recorded by the ASMs. These conventional scour chains were deployed in September 2010 using the method of Klassen and Northcote (1986) and were recovered during July and August 2011. The ASMs were located using the RTK-GPS and excavated in February, July, and August 2011. The time series of orientation for each accelerometer was analyzed, and deviations of greater than 15 degrees from vertical, were interpreted as a disturbance of the surrounding gravel matrix at the mid-point of the 8-cm accelerometer casing.

**RESULTS**

Twenty-four of the 26 deployed ASMs were recovered, of which 17 recorded streambed disturbance and 7 recorded no streambed disturbance. At some locations, ASMs recorded one discrete shift and at other locations, continuous movement of the ASMs was detected during high-flow events. Most disturbances were recorded at the upper accelerometers, but three ASMs recorded disturbance at both the upper and lower accelerometers. Only one ASM recorded disturbance during a low-magnitude high-flow event in December 2010 (peak flow: 65 $m^3/s$; 1.4-year recurrence interval) on the rising limb of the hydrograph when the discharge was 64 $m^3/s$. Fourteen of the 26 ASMs were first disturbed during the rising limb of the hydrograph during a larger high-flow event in January (fig. 3; peak-flow 159 $m^3/s$; 7-year recurrence interval). Two other ASMs were first disturbed well after the peak of this high-flow event including a single ASM that remained undisturbed for 16 days after the peak, but was finally disturbed when streamflow had decreased to 51 $m^3/s$. Four conventional scour chains deployed within 3 m of two ASMs recorded a mean total scour depth of 37 ±10 cm compared to 39 cm and 35 cm recorded by the two nearby ASMs. Mean disturbance depths measured at all ASM locations were 29 ±10 cm.

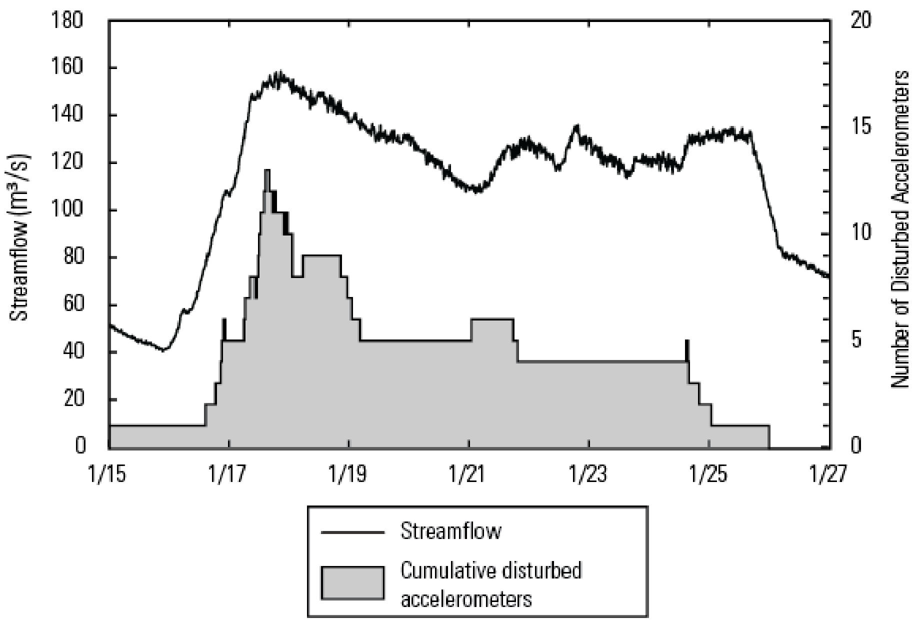


**Figure 3.** Disturbance of accelerometers during the January 2011 high-flow event.

## DISCUSSION AND CONCLUSIONS

ASMs recorded the timing of streambed disturbance and stability in the Cedar River during two high-flow events. The total disturbance depths recorded during the high-flow events were similar to conventional scour chain measurements. Unlike conventional scour chains that record the total scour over an entire high-flow event, streambed-disturbance dynamics during high-flow events were documented by the ASMs (fig. 3). In addition to recording the timing of streambed disturbance, ASMs recorded the onset of streambed stability, which was inferred to result from fill deposition. At some locations, ASMs recorded one discrete shift, which was inferred to be streambed disturbance but not necessarily scour to the accelerometer (fig. 4*A*). At several locations, ASMs recorded discontinuous periods of disturbance, including scour when accelerometers shifted constantly, and stability during the high-flow events (fig. 4*B*), suggesting intermittent scour and fill, and therefore, bed elevations and bedload transport consistent with the stochastic nature of sediment transport at small scales.

ASMs have several advantages compared to other types of scour monitors with respect to their data-collection capability and durability. Unlike several other scour monitors, ASMs do not protrude above the streambed surface thus minimizing the alteration of local hydraulics that may influence patterns of scour. In addition, ASMs are entirely self-contained within PVC and do not have any moving parts or exposed electronics, making them resistant to damage during the bedload-transporting events they were designed to monitor. In addition to measuring the timing of streambed disturbance, ASMs, unlike other scour monitors, also measure the timing of streambed stability resulting from fill deposition. An observed limitation of the ASMs was that the timing of streambed disturbance recorded by ASMs was limited to the depths at which the 8-cm ASMs were placed, providing less vertical resolution than other scour monitors.

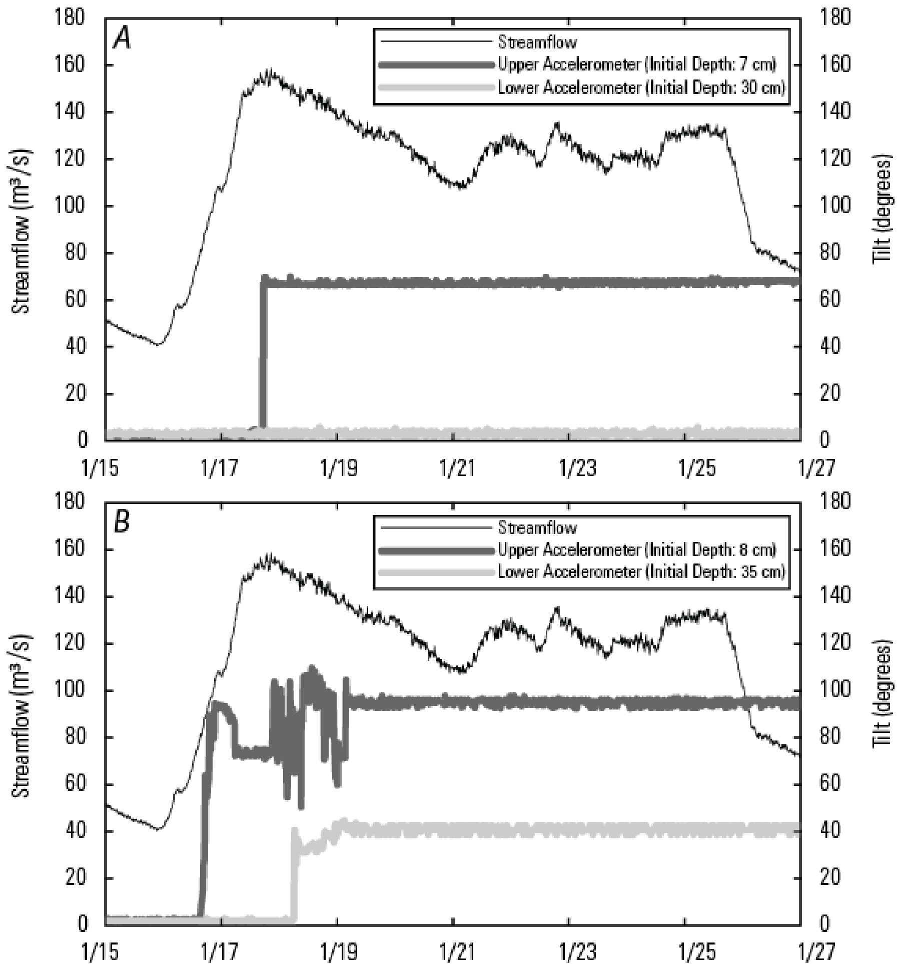


**Figure 4.** Streamflow and tilt of the upper and lower accelerometers for two ASMs where (*A*) one discrete disturbance and (*B*) multiple disturbances occurred.

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