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The timing of scour and fill in a gravel-bedded river measured with buried accelerometers

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SUMMARY

A device that measures the timing of streambed scour and the duration of sediment mobilization at specific depths of a streambed was developed using data-logging accelerometers placed within the gravel substrate of the Cedar River, Washington, USA. Each accelerometer recorded its orientation every 20 min and remained stable until the surrounding gravel matrix mobilized as sediment was transported downstream and scour reached the level of the accelerometer. The accelerometer scour monitors were deployed at 26 locations in salmon-spawning habitat during the 2010–2011 flood season to record when the streambed was scoured to the depth of typical egg-pocket deposition. Scour was recorded at one location during a moderate high-flow event (65 m^3/s; 1.25–1.5-year recurrence interval) and at 17 locations during a larger high-flow event (159 m^3/s; 7-year recurrence interval). Accelerometer scour monitors recorded periods of intermittent sediment mobilization and stability within a high-flow event providing insight into the duration of scour. Most scour was recorded during the rising limb and at the peak of a flood hydrograph, though some scour occurred during sustained high flows following the peak of the flood hydrograph.

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1. Introduction

Streambed scour, i.e. the mobilization of streambed substrate during high flows, influences geomorphic processes like sediment transport (DeVries, 2002) and benthic organisms including periphyton (Biggs et al., 1999; Matthaei et al., 2003; Segura et al., 2011), macroinvertebrates (Cobb et al., 1992; Death and Winterbourn, 1995; Townsend et al., 1997), and incubating salmon embryos (Montgomery et al., 1996; Rennie and Millar, 2000; DeVries, 2008). The effect of streambed scour on stream ecology has been studied through hydraulic modeling (e.g., May et al., 2009; McDonald et al., 2010) and the deployment of scour monitoring devices in the field (Montgomery et al., 1996; Nawa and Frissell, 1993). Most field-collected scour data describe the spatial distribution of depth of scour (removed sediment) and fill (deposited sediment) that occurs during a flood or flood season. These data have been measured by different types of scour monitors including scour chains (Emmett and Leopold, 1965; Lisle, 1989) and sliding-ball monitors (Klassen and Northcote, 1986; Tripp and Poulin, 1986; Nawa and Frissell, 1993).

Previous scour chain and sliding-ball monitor investigations have shown that much variability exists in the range and spatial distribution of scour depths; while the maximum scour depths in parts of the channel may greatly exceed the thickness of the surface armor layer, little to no scour may be observed in other parts of the channel (Hassan, 1990; Haschenburger, 1999; Rennie and Millar, 2000). This variability in scour depths reflects the complex interaction between hydraulic forces acting on the streambed, which are not only influenced by heterogeneous bed material and channel morphology but also by changing hydraulic conditions during a flood event and even temporary obstructions such as passing large woody debris. Although the spatial variability in the depth of scour is well established in a variety of fluvial systems, the temporal record of scour and streambed mobilization during high flows has not been intensively studied and few field methods to measure it exist.

Scour monitors that record the timing of streambed scour are necessary to assess the relation between streambed scour and geomorphic conditions during a high-flow event. Methods to measure the timing of scour during a flood include continuous monitoring of neutrally buoyant radio transmitters buried within stream gravels (Cascades Environmental Services, 1991). Dislodgement indicated when bed scour reached the transmitter burial depth; however, this approach required continuous monitoring by field personnel precluding precise determination of the timing of scour. In addition, transmitters were lost upon dislodgement preventing determination of the timing or depth of subsequent fill. DeVries

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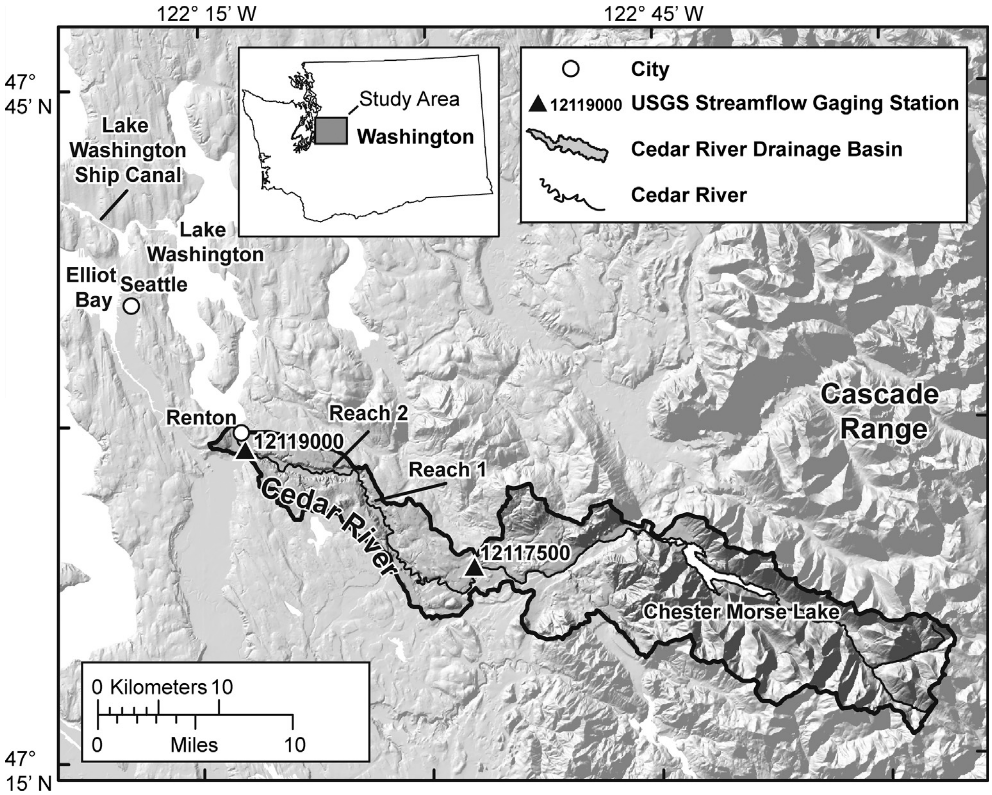

Fig. 1. Location of study reaches within the Cedar River drainage basin, Washington.

et al. (2001) developed another method called the electronic scour monitor for determining the timing of streambed scour by modifying conventional sliding-ball scour monitors so that they recorded when a magnet within each ball passed a magnetic reed switch after it was exhumed from the streambed.

The objective of this study was to present a new scour-monitoring method based on data-logging accelerometers installed in the gravel substrate of a streambed and evaluate their ability to record the temporal history of scour in salmon spawning habitat. The accelerometers can be deployed at one or more depths at single locations to measure the time when scour reaches critical depths of the streambed and are capable of recording over several months during a flood season. Moreover, accelerometers record the duration of streambed mobilization providing insight into bedload transport in the field. Time series of the orientation of individual accelerometers were recorded at 26 locations in the Cedar River, Washington (Fig. 1), and were interpreted with respect to the mobilization and stabilization of the adjacent gravel substrate during the 2011 Water Year (October 2010–September 2011).

2. Cedar River: Geography, hydrology, and salmonid spawning

The Cedar River flows 72 km from its headwaters in the Cascade Range into Lake Washington (Fig. 1) and has been regulated by a dam at the outlet of Chester Morse Lake since the early twentieth century. Flow regulation and floodplain alterations, including bank stabilization structures such as revetments, have contributed to channel narrowing, reduced number of side channels, limited channel migration, and reduced sediment supply (Perkins, 1994; Gendaszek et al., 2012). Cedar River hydrology is governed by the temperate, humid Pacific Northwest climate (Mass, 2008). Summers are dry and warm and winters are wet and mild. Flood hydrology is dictated by heavy and prolonged winter-rain events (Neiman et al., 2011) and snowmelt during the spring. The largest peak-flow events typically occur between November and January, while a smaller snowmelt freshet occurs in May or June, which is partially retained by Chester Morse Lake for municipal water supply during the summer. Mean annual streamflow of the Cedar River at Renton was 18.8 m^3/s between 1946 and 2010. During this period, the highest mean monthly streamflow occurred during January (31.1 m^3/s) and the lowest mean monthly streamflow occurred during August (5.4 m^3/s). The highest instantaneous streamflow recorded at this gage was 300 m^3/s on 24 November 1990 (Gendaszek et al., 2012).

The Cedar River is managed to provide 70% of the City of Seattle's municipal water supply, limited flood control along its suburban and urban river corridor, and spawning and rearing habitat for several species of anadromous salmonids. These salmonids include native Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*) and introduced sockeye salmon (*Oncorhynchus nerka*). During spawning, female salmonids dig depressions called redds, deposit eggs, and cover them with a clean layer of gravel where they incubate for several weeks to months prior to the emergence of fry (e.g., Peterson and Quinn, 1996). In the Pacific Northwest, the incubation period of several salmonid species coincides with the late fall and early winter flood season. In response to the listing of two salmonid species under the federal Endangered Species Act, Chinook salmon and steelhead trout, resource managers of the Cedar River created a habitat conservation plan (Seattle Public Utilities, 2000) that included protocols to regulate peak flows to minimize scour of salmonid embryos incubating in river gravels.

During the development of salmonid embryos, scour of gravel from the streambed to the depth of egg pockets within redds and the resulting entrainment or crushing of salmonids embryos may adversely affect the survival of salmonid embryos and thus constrain salmonid population viability (Montgomery et al., 1996; LaPointe et al., 2000). In addition, salmonid-embryo survival may