Measuring Fluvial Sediment Transport with Tracer Stones

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Abstract

Tracing the motions of individually identifiable sediment particles over multiple floods offers a unique and detailed view of fluvial sediment transport processes. Individual particle trajectories can be used to identify the flows required to initiate sediment transport, to measure particle travel distances and the duration of immobile periods, to estimate sediment flux, and to illuminate the interaction between channel morphology and sediment transport. In particular, coarse sediment equipped with radio frequency identification (RFID) technology in the form of passive integrated transponder (PIT) tags allow individual particles to be tracked over many years with very high recovery rates. The PIT tags equip each clast with a unique identifier that can be detected from a distance with little interference from water or sediment, allowing particles to be located and identified without disturbing the stream bed. I describe and discuss RFID tracer experiments in several rivers including Halfmoon Creek in Colorado (investigating the nature of fluvial sediment dispersion), the Methow River in Washington (assessing the mobility of gravel bars along a large river), and the Bighorn River in Montana (the maintenance and sustainability of side channels on a regulated river).

Introduction

Tracking the trajectories of individually labeled bedload particles provides a uniquely detailed view of fluvial sediment transport. Knowledge of individual particle trajectories can be used to identify transport thresholds, to measure travel distances and storage times, to estimate bedload fluxes, and to observe the feedbacks between channel morphology and sediment transport.

Radio Frequency Identification technology (RFID) in the form of small, inexpensive Passive Integrated Transponder (PIT) tags can be used to equip gravel-sized and larger bedload clast with an identifying number that can be detected and read out at a distance with little interference from water or sediment. The exact detection range depends on the size and type of antenna used to energize the tag, but is generally on the order of 0.5 – 2m. The antenna provides the power the PIT tags use to transmit the unique identifier when within range (hence the term ‘passive’), so the tags require no battery and can last for decades. The use of PIT tagged gravels to investigate gravel transport dynamics was introduced about a decade ago and studies in relatively small, wadeable streams have produced tracer recovery rates above 90% for years after tracer installation. In this extended abstract, I discuss one of these early RFID tracer studies and two ongoing tracer experiments.
Halfmoon Creek Tracer Experiment

In May 2007, Greg Tucker of the University of Colorado and I deployed 893 PIT tagged tracer stones in Halfmoon Creek, a small alpine watershed in the Upper Arkansas Basin near Leadville, CO. The study was designed to investigate nature of the probability distributions of travel distances and storage times that govern tracer dispersion. We surveyed the positions of the tracers every summer following the spring snowmelt flood from 2007 to 2016, resulting in a decade long record of tracer transport observations. Recovery rates exceeded 90% in all years but one.

Early results showed that tracer transport distributions were best described by a thin-tailed probability distribution (Figure 1a) [Bradley et al., 2010] a result that was later confirmed [Bradley, 2017]. Similar studies have reached the same conclusion, ruling out heavy-tailed step lengths as a cause of anomalous diffusion [e.g. Phillips et al., 2013]. Later results showed anomalous super-diffusion caused by an observable heavy-tailed distribution of tracer storage times (Figure 1b) [Bradley, 2017], confirming what had been suspected [Martin et al., 2012; Phillips et al., 2013; Voepel et al., 2012] for several years. I attribute the high probability of long storage times to trapping by gravel bars (Figure 2).

Figure 1. a) The distribution of tracer travel distance is thin-tailed. Tracer displacements are normalized by the mean displacement over that interval. b) The distribution of tracer storage times are best modeled by a truncated Pareto (TP) distribution with a tail parameter of 0.67. Modified from Bradley [2017].
Methow River Sugar Levee Gravel Bar Mobility

The Methow River near Twisp, WA is confined by the Sugar Levee along the right bank upstream of a very large right bank point bar Figure 3. Across from the point bar, the river is rapidly eroding into private property. My hypothesis is that the levee is limiting the sediment deposition space on the point bar across from the levee, causing sediment to move rapidly through the levee reach and accumulate on the downstream point bar. If the levee were removed or set back, the river would be able to move to the right and gravel could accumulate on the opposite point bar, possibly reducing annual deposition on the downstream point bar and slowing bank erosion. To test this hypothesis and gain a better understanding of the movement of sediment through this reach, Reclamation deployed 600 RFID tagged gravel and cobble clasts on bars upstream of and across from the levee in the summer of 2018. The positions of the tracer stones will be surveyed annually following the spring snowmelt for 3 years. Direct observation of where tracer gravel accumulates (and does not accumulate) will provide insight into the interaction between the levee and the sediment dynamics.
Bighorn River Side Channel Sediment Transport

Reclamation deployed 400 RFID tracer stones in side channels of the Bighorn River below Yellowtail Dam in Montana in the winter of 2012 as a part of an effort to evaluate sediment transport through side channels and side channel longevity (Hilldale, 2012). Side channels provide important fish habitat and the factors that contribute to their persistence are not well understood. The tracers were recovered for several years and their motion was used to evaluate incipient motion thresholds in the context of the flows released from Yellowtail Dam. Reclamation will re-survey the tracer locations again in 2019 and 2020 as a part of study to evaluate how the Bighorn River side channels have responded to several years of high flows since the end of the original study.
References


