Continuous Surrogate Bedload Measurement on the Elwha River Following Dam Removal

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ABSTRACT

The U.S. Department of the Interior plans to remove Elwha and Glines Canyon Dams on the Elwha River, near Port Angeles, Washington, U.S.A. to restore the ecosystem and native anadromous fisheries. By 2012, when dam removal may begin, the two reservoirs are predicted to contain 16 million m^3 of sediment from the 840 km^2 watershed. This will be the largest volume of reservoir sediment erosion associated with dam removal in North America and, therefore, offers a unique learning opportunity. The Bureau of Reclamation, in cooperation with the National Park Service, is currently installing a series of bedload impact sensors to continuously monitor the bedload movement following dam removal. The use of a surrogate method of sediment transport measurement is an attempt to supplement classic physical sampling of bedload. The surrogate methods to be used on the Elwha River are a result of research performed jointly by the Bureau of Reclamation and the National Center for Earth-Surface Dynamics (St. Anthony Falls Laboratory, University of Minnesota), funded by the Federal Interagency Sedimentation Project (FISP). This research builds on similar bedload measurement developments in the U.S.A, Norway and Switzerland. Three different sensor types will be used, including geophones, accelerometers and hydrophones. The geophones and accelerometers will be attached to the underside of steel plates, mounted to a steel structure that spans the channel width of 38 m. The steel structure contains a series of 73 steel plates, acoustically isolated from each other and mounted on the downstream side of a concrete weir. Hydrophones will be employed outside of the steel structure. Installation of the three sensors and steel structure will be completed by fall 2009. Following installation, a field calibration of the sensors will take place. This site will be ideal to test other surrogate bedload measurement methods due to the reliability of coarse sediment being transported past this site.

INTRODUCTION

In anticipation of dam removal, impact sensors are being installed across the bed of the Elwha River to continuously measure bedload. The removal of two large dams on the Elwha River, near Port Angeles, Washington, U.S.A. (Figure 1), will result in the largest controlled release of reservoir sediment associated with any dam removal in North America and, therefore, offers a unique learning opportunity for sediment transport and management.

Figure 1. The Elwha River is located within northwest Washington State, U.S.A.

Three organizations have cooperated in this research project: The Bureau of Reclamation has designed and fabricated the bedload impact sensors. The University of Minnesota St. Anthony Falls Laboratory is developing an algorithm to process the electrical signals from the sensors and developing the relationship between bedload impacts and mass transport rates (see the companion paper in these proceedings by Marr, et al.). The National Park Service and their contractors are installing the bedload impact sensors.

The U.S. Department of the Interior has purchased, and plans to remove, Elwha and Glines Canyon Dams on the Elwha River, to restore the ecosystem and native anadromous fisheries (U.S. Department of the Interior, National Park Service, 1996, 2004, and 2005). After dam removal, these fish will have access to more than 100 km of mainstem and tributary habitat. Elwha Dam is a 32-m high concrete gravity dam that was constructed 7.9 km upstream from the river mouth in 1913 (U.S. Department of the Interior, National Park Service, 1996). Glines Canyon Dam is a 64-m high concrete arch dam that was constructed 21.7 km upstream from the river mouth in 1927.

The headwaters of the Elwha River begin within Olympic National Park and flow northward to the sea in the Strait of Juan de Fuca (Figure 2). The river flows through a series of alluvial valleys and bedrock canyons. Average river slope in the lower 8 km is 0.4 percent. The mean annual river discharge is 42 m^3/s. The 2-year and 100-year flood peak discharges are 370 and 1,270 m^3/s, respectively.

The reservoirs behind the two dams have trapped the entire upstream load of sand and gravel (67-year average of 82,000 m^3/yr) and are estimated to have trapped 70 percent of the silt and clay load (Randle et al., 1996). By 2012, when dam removal may begin, the two reservoirs are predicted to contain 8.4 million m^3 of silt and clay-sized sediments and 8.0 million m^3 of sand and gravel-sized sediments. The two reservoir deltas are each about 3,000 m upstream from the dams.

ELWHA RIVER RESTORATION PLAN

The Elwha River restoration plan is to concurrently remove both dams in controlled increments over a two- to three-year period and allow the river to erode a portion of the reservoir sediments for transport to the sea. Predictions of the sediment impacts associated with dam removal are based on the 1994 drawdown experiment of Lake Mills (Childers et al., 2000), a mass-balance numerical model (Randle et al., 1996), and physical modeling of the reservoir sediment erosion (Bromley et al., 2005). Between one-quarter and one-third of the sand and gravel-sized sediments (1.7 million to 2.4 million m^3) are expected to erode from the reservoirs and be transported downstream to the sea as bed-material load (Randle and Bountry, 2008). Between one-half and two-thirds of the silt and clay-sized sediments (4.1 million to 5.0 million m^3) are expected to erode from the reservoirs and be transported downstream to the sea as suspended load (Randle and Bountry 2008). The remaining reservoir sediments are expected to stabilize and become covered with woody vegetation over the long term.

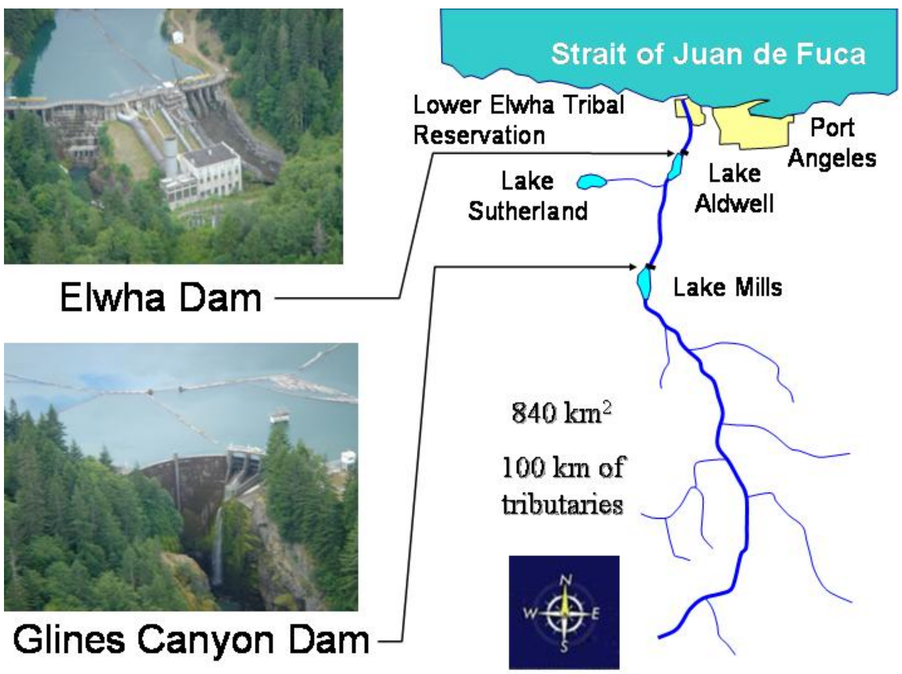

Figure 2. Elwha and Glines Canyon Dams are located on the Elwha River near Port Angeles, Washington, U.S.A.

Downstream water users will be protected from increased suspended sediment loads by the construction of three water treatment plants, new wells, and a new water diversion facility with improved fish passage. Downstream landowners will be protected from potential increases to flood stage from aggradation by raising the height of existing levees and the construction of new levees (U.S. Department of the Interior, National Park Service, 2004 and 2005). Dam removal over a two to three-year period is considered fast enough to limit the sediment impacts to only a few year classes of fish, but slow enough that impacts to downstream water users and landowners can be tolerated (U.S. Department of the Interior, National Park Service, 1996).

ADAPTIVE MANAGEMENT

A sediment adaptive management plan will be used to monitor reservoir sediment erosion and downstream river channel deposition and water quality during dam removal. Reservoir drawdown and dam removal will proceed as planned if the actual sediment impacts do not exceed predictions and if the new water treatment plants and flood control levees can accommodate the increases in suspended sediment concentration and river-bed aggradation. Initially, monitoring will focus on the erosion and redistribution of reservoir sediments. Once sediments are released from the reservoirs, downstream monitoring will focus on turbidity and on aggradation along the downstream river channel. Early detection of significant channel-bed aggradation will trigger additional monitoring. Detection of system-wide aggradation or high sediment concentrations that begin to approach flood-control or water-treatment capacities will trigger a temporary halt to reservoir drawdown and dam removal. If localized problems are identified through monitoring, then attempts will be made to treat the problem locally.

Riverbed aggradation will not occur in the Elwha River downstream of the dams without the deposition of gravel- and cobble-size sediments. Herein lies the tremendous benefit of continuous monitoring of bedload downstream of the dams, which not only provides a cumulative measure of bedload but will also provide information about the manner in which sediment moves past the site. This is an improvement over temporally discrete bedload measurements. The large supply of coarse sediment from dam removal provides a unique opportunity to measure bedload without the usual dependence on hydrology.

BEDLOAD IMPACT SENSORS

Direct, physical bedload measurement is labor intensive and frequent measurements are cost prohibitive. Additionally, these measurements are difficult at night or during floods. In the United States, there is no accepted standard instrument for the direct measurement of bedload in gravel-bed rivers. Surrogate measurement of bedload using impact sensors was successfully demonstrated in Switzerland (Rickenmann and McArdell, 2005). Geophones attached to the underside of steel plates were installed at a weir crest to measure and count the impacts from gravel particles that are at least 10 mm in diameter. Surrogate measurements of bedload can be made continuously and are not limited by floods or darkness.

The removal of the rock diversion dam and subsequent replacement with a concrete weir on the Elwha River provided an opportunity to install bedload impact sensors across the crest of the new diversion weir (Figure 3). This effort required dewatering of the site by constructing coffer dams and a river diversion channel. Dewatering the site was essential for the installation of the bedload impact sensors.

Figure 3 caption:

Figure 3. New diversion weir (river km 5.6) constructed across the Elwha River in October 2008. The picture on the right shows the low flow notch during construction. Flow direction in both figures is from left to right.

The new diversion weir consists of a vertical wall and rock ramps to enable fish passage (Figure 4). The vertical wall was constructed from concrete panels. The crest of the wall is protected by a stainless steel cap. Boulders within the rock ramp were grouted near the wall.

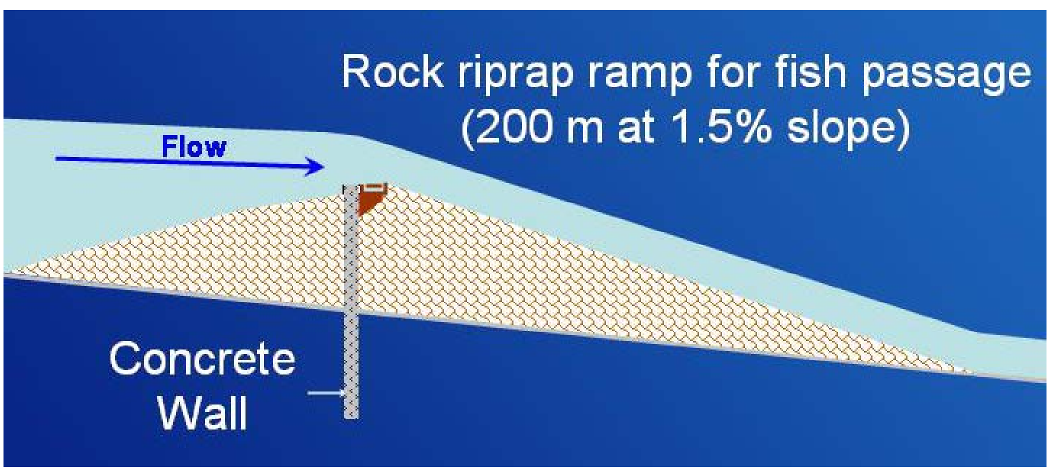

Figure 4. The longitudinal river profile shows the concrete diversion weir (labeled as wall) and rock ramps constructed to enable fish passage.

The bedload impact sensors are attached to the downstream side of the steel cap on the concrete weir wall (Figure 5). A total of 73 impact sensors are being installed along the weir crest. Each bedload impact sensor consists of an acoustically isolated steel plate with a geophone or accelerometer attached to the underside. Each stainless steel plate has the dimensions of 35 cm in the longitudinal direction, 50 cm in the lateral dimension, with a thickness of 1.5 cm. At least one hydrophone will be deployed in the river adjacent to the water intake structure (Figure 3).

The bedload impact sensors are housed in carbon steel frames, which are structurally supported and secured to the weir wall by carbon steel channel and gusset plates (Figure 6). The electrical cables for the geophones and accelerometers are routed laterally through conduit in the steel box frames (Figure 7) to a computer housed in a weather proof cabinet located on top of the water intake structure.

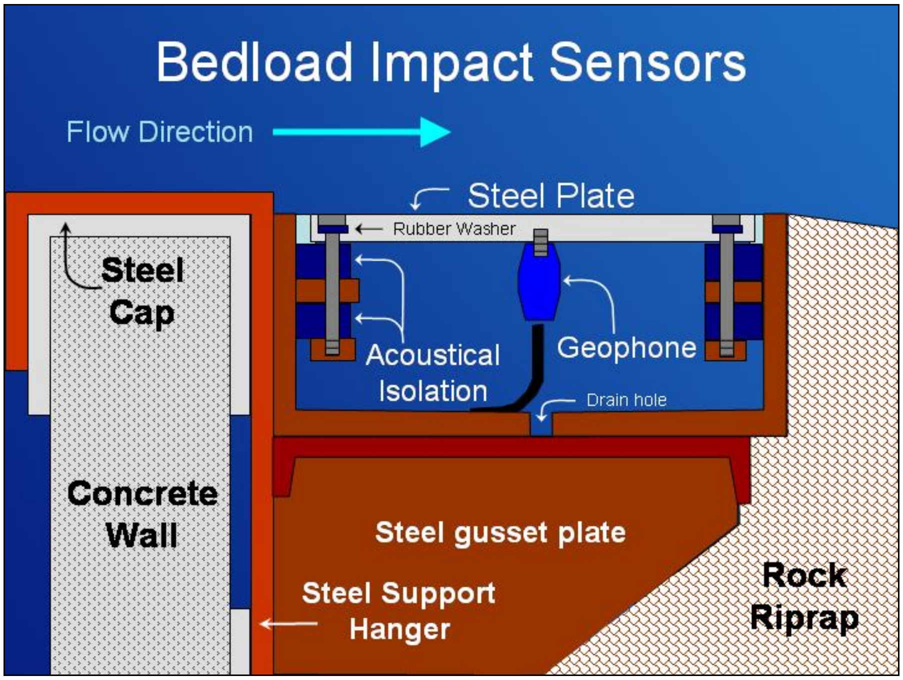

Figure 5. A cross section detail of the weir crest shows the bedload impact sensors and steel gusset support plates attached to the steel cap on the concrete wall.

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Figure 6. Fabricated structural supports are displayed upside down in the Bureau of Reclamation's machine shop in Denver, Colorado.

Figure 7. Photograph of bedload impact sensor steel plates and frames obliquely show the cross section of the assembly.

FABRICATION AND INSTALLATION

The structural supports (steel support frames, gusset plates, and hangers; Figure 6) were fabricated and installed along the entire length of the weir crest during summer 2008 by a contractor for the National Park Service. The bedload impact sensors and steel frames (Figure 7) were fabricated and installed along the low-flow portion of the weir crest during this same time period (12 plate/sensor combinations). Fabrication and installation of the remaining bedload impact sensors and steel frames will continue for the remaining high-flow portion of the weir crest length during summer 2009.

CALIBRATION

Although the relationship between bedload impacts and the mass transport rate will be calibrated in the laboratory (see the companion paper in these proceedings by Marr, et al.), field calibration is planned. Deployment of the Elwha bedload sampler from a raft on the flat surface of the steel plates should provide an excellent location for bedload measurements. The Elwha sampler is 10.2 cm high and 20.3 cm wide and has an entrance-to-exit area expansion ration of 1.4 (Childers, et al., 2000). Collecting bedload measurements with a sampler placed on a sill has been shown to improve sampling accuracy compared to measurements taken when placing the sampler directly on the bed material (Bunte et al, 2007). A series of bedload measurements should provide the data necessary for field calibration of the bedload impact sensors. In addition, the volume and grain size distribution of sediments eroded from the reservoirs will be measured before and during the course of dam removal. These measurements will provide an estimate of the total mass transported past the bedload impact sensors due to dam removal.

CONCLUSIONS

The controlled release of reservoir sediment from the removal of two large dams on the Elwha River will create a dynamic environment from which to measure bedload. The bedload impact sensors installed along the weir crest at river km 5.6 will provide a surrogate means to continuously measure the bedload of the Elwha River. The deployment of a hydrophone provides yet another opportunity to test new technology for measuring bedload transport. The steel plates of the bedload impact sensors will also provide an excellent surface for the direct measurement of bed-material load using more traditional physical bedload sampling methods that can be used for field calibration. The data from bedload measurements will help the sediment adaptive management program determine the rate at which coarse sediment, eroded from the two reservoirs, is being transported through the river channel downstream of Elwha Dam.

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